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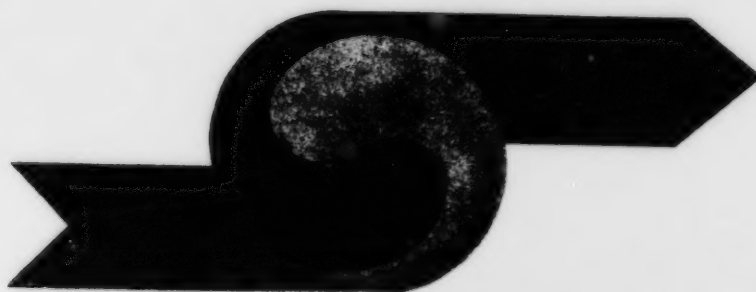
Division de l'énergie

Heat Pump
Program

Programme des pompes
de chaleur

Industrial Heat Pump Application in a Milk Plant

Chalifour, Marcotte et Associés Inc.
March 1983



Canada

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INDUSTRIAL HEAT PUMP APPLICATION
IN A MILK PLANT

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1. INTRODUCTION

The milk industry is one of the major energy consumers in the Canadian Industrial sector. In the food industry alone, it is probably the largest energy consumer. While the energy cost represents a low percentage of the total industry expenses, it is likely to remain an important factor of net profitability of a milk transformation plant.

In the past, the low energy cost did not warrant process efficiency improvements. The sharp increase of energy cost, particularly the cost of heavy grade oil (Bunker "C") has changed the currently used cost/benefit calculation. The actual cost of this energy source is almost ten (10) times what it was ten years ago.

An important quantity of milk which cannot be sold in its natural form, has to be processed to reach a final commercial product which could be stocked for a long period of time without any deterioration.

The different processes used in the milk transformation industry can be divided into six main products such as:

- butter
- cheese
- cream
- evaporated milk
- dry powder milk
- dairy desserts



Because of the nature of the final products, some of these processes require a large amount of energy. This is the case of dry milk and evaporated milk production which require an important reduction of the moisture content of the whole milk.

In order to adapt the industrial operations to the higher energy cost situation, new and more efficient transformation technics must be implemented. Due to the risk involved and the lack of knowledge of the several energy conservation opportunities, little has yet been done to improve the process efficiencies.

In the plant studied, the two major energy users are:

- the milk evaporator
- the milk dryer (atomizer)

The milk evaporator uses mainly fossil fuel generated steam. The milk dryer energy source is electricity which is rather exceptional for this type of process. We expect that the fossil fuel replacement figure would be better for most of the other plants.

The availability of a substantial amount of waste heat from the evaporator, together with the large energy requirements of the dryer, are the essential elements of a profitable heat pump installation.

The importance of heat recovery on the barometric condenser of the vacuum evaporator has long been recognized. Various heat recovery systems have been proposed and some were implemented. Most of these involve air and water heating at a relatively low enthalpy level.



The installation of a heat pump represents a major breakthrough in the actual heat recovery technics. While the major part of the recovered heat will be used for the dryer, several other utilisations have been studied and will be incorporated to the heat pump installation. The drawing No SK1 in annexe I shows the schematic of the whole installation including the modifications that will be implemented to several processes.

Further improvements could be evaluated in order to achieve standardized heat pump application which will upgrade most of the actual heat wasted from the vacuum evaporator. Such a study would be a net profitable investment for the whole milk industry throughout the country.



2. OBJECTIVES

2.1 The general objectives

- I To spread heat pump uses into areas with little or no previous operating experience.
- II To identify areas where equipment development is required.
- III To determine design parameters which are important in heat pump waste heat recovery systems.
- IV To promote extensive economic waste heat recovery.



2. OBJECTIVES

2.2 The specific objectives of Phase A

- I The identification by process design technique of the optimum sizes and performance of heat pumps in the proposed system.
- II The selection of the equipment and the preparation of designs of process modifications to assure successful implementation meeting all design and regulatory code requirements.
- III The preparation of a statement of economic viability, capital cost, operating cost, benefits and payback as perceived by the plant operator.
- IV The preparation of a statement of energy savings for this plant and an estimate of its effect on a nation-wide basis.
- V Recognizing that readily available and proven equipment is to be used to permit early implementation, the review of the research and development areas which may yield further benefits, (e.g. heat materials technology, instrumentation and control technology).
- VI The discussion of the need for any new operating or maintenance skills and its impact upon operational management.



3. AVAILABLE HEAT SOURCES

3.1 General description

The main activity of the milk transformation plant under study is the milk condensation process which is used to produce canned evaporated milk, as well as powder dry milk. These two forms of concentrate represent a sufficient reduction in weight and volume to make storage, transportation and distribution more economically feasible.

A large part of the plant's energy consumption is used for the evaporation of water which forms the major part of the milk content. The evaporation process occurs in a low temperature evaporator which was developed for use in the milk industry. This type of evaporator represents the successful application of a number of engineering principles. Without going into too many details, the plant uses a four-effect evaporator which operates at reasonable efficiency. It uses approximately 0,192 kg of steam to evaporate 1 kg water.

Several modifications to this equipment would permit to increase its efficiency. Some of these modifications are reviewed in chapter 9 of this study.



Actually, for the major use of the evaporator which is skim milk concentration, the water evaporation process uses 4 600 kg/hr (10 100 lbs/hr) of steam when the skim milk is fed in the evaporator at a rate of 25 000 kg/hr (55 000 lbs/hr). The mass and energy balance tells us that this amount of energy supplied will end up as excess heat in the final stage condenser of the process. In order to maintain the vacuum required for a continuous operation, the evaporated water is condensed in a barometric condenser which uses a large amount of cooling water. This will be the main heat source of the heat pump installation.

3.2 Waste energy available from the evaporator

In the original concept of the evaporator, several low enthalpy condensates are rejected in a hot well (see photo) which is drained to the river (see photo). When the evaporator is used for high heat skim milk concentration, the theoretical values of all the evaporator water outputs (heat sources) are given in table 3.1.

TABLE 3.1 DESIGN VALUES FOR THE WASTE WATER STREAMS FROM THE PSM EVAPORATOR

Identification of heat source	Water flow L/min (USGPM)	Water Temperature		Approximate heat rejected (if water is cooled to 70°F)	
		°C	(°F)	kW	(MMBTU/hr)
Barometric leg from condenser:	1 967 (519)	35	(95)	1 900	(6,5)
1st and 2nd effect condensate output:	166 (44)	69	(156)	550	(1,89)
3rd and 4th effect condensate output:	221 (58)	53	(127)	480	(1,6)
Barometric legs of steam ejectors:	95 (25)	65	(150)	290	(1,0)

Figure 3.1 Warm waste water collector (evaporator hot well)



Figure 3.2 Warm waste water drain outlet to the river



3.2 Waste energy available from the evaporator (cont'd)

Plant management already knows the importance of heat recovery resulting in a reduction of the net energy input required for the processes. Various heat recovery systems have been proposed and a few are already implemented. All of them produce by-product energy at relatively low enthalpy levels.

At the present time, waste water is being used directly for the following two purposes:

- . Hot condensate (69°C) is used as boiler feed water
- . Medium temperature condensate is used as warm water for cleaning purposes

Although important from an energy saving stand point, these applications can only make limited use of waste heat from the evaporator.

Because of its low enthalpy level, no utilisation has been found for the output of the barometric condenser. A major breakthrough may be arrived at if this tremendous amount of energy can be upgraded and used to substitute fossil fuel generated process steam or electricity.



The analysis of the several methods using waste water directly for other uses, has shown that only the condensate output from the 1st and 2nd evaporator effect, which is already being used as boiler feed water, should be left as it is. Despite the low temperature level of this process condensate, it is the main make-up water source of the boilers. The contamination level of this process condensate is very low and it needs less chemical products than the use of fresh water make-up.

In order to obtain an accurate evaluation of the heat source availability for a heat pump installation, on site waterflows and temperatures were measured on most of the evaporator water outputs.

The evaporator is not always used for high heat skim milk concentration and the nature of the final concentrate does affect the waste water temperatures and flows.

The results of the measurements are as follows:

3.2.1 Barometric condenser

The following table compares some theoretical values with actual measurements taken on site on the barometric condenser water streams. It must be mentioned that when the measurements were taken the water flow was very low because the cooling water inlet temperature was well below the design value.

TABLE 3.2 THEORETICAL AND ACTUAL VALUES OF THE WATER USE ON THE BAROMETRIC CONDENSER

<u>Description</u>	<u>Theoretical</u>	<u>Actual</u>
Cooling water temperature at the inlet °C (°F)	21 (70)	1 (34)
Cooling water temperature at the outlet °C (°F)	35 (95)	40 (105)
Cooling water flow L/min. (US GPM)	1 967 (520)	530 (140)
Total energy output kW (BTU/hr) (1)	1 900 (6 500 000)	1 455 (4 970 000)

Note (1) Based on the temperature differential between the cooling water inlet and outlet.

3.2.2 Condensate output, pump P-5

This output stream comes from the 1st and 2nd effect of the evaporator. Its main use is and will remain to provide boiler feed water. The excess water however will be used as a heat source for the high temperature heat pump.

TABLE 3.3 THEORETICAL AND ACTUAL VALUES OF WASTE WATER
CHARACTERISTICS FROM THE 1ST AND 2ND EFFECT

<u>Description</u>	<u>Theoretical</u>	<u>Actual</u>
Condensate temperature °C (°F)	69 (156)	65 (150)
Condensate flow rate L/min (US GPM)	166 (44)	137 (36)
Total energy output kW (BTU/hr) (1)	550 (1 890 000)	420 (1 440 000)

Note (1) If the condensate is cooled down to a temperature of 21°C (70°F)

3.2.3 Condensate output pump P-9

This condensate output comes from the 3rd and 4th effect of the evaporator. It is now used as warm process water for cleaning purposes on a temporary basis. It is mixed with a small amount of milk and could not be used as cleaning water on a yearly basis. Because of the higher temperature level of this water, it will be used entirely as the heat source of the high temperature heat pump. The following table compares some theoretical values with measurements taken on site on the 3rd and 4th condensate output.

TABLE 3.4 THEORETICAL AND ACTUAL VALUES OF WASTE WATER CHARACTERISTICS FROM THE 3RD AND 4TH EFFECT

<u>Description</u>	<u>Theoretical</u>	<u>Actual</u>
Condensate temperature °C (°F)	53 (127)	53 (127)
Condensate flow rate L/min. (US GPM)	221 (58)	190 (50)
Total energy output kW (BTU/hr) (1)	480 (1 650 000)	415 (1 425 000)

Note (1) If the condensate is cooled down to a temperature of 21°C (70°F)



3.2.4 Barometric legs of steam ejectors

The accurate measurement of the water output from the steam ejector barometric legs was not possible because their outlet in the hot well must always be kept below the water level in order to maintain the required negative pressure in the evaporator. The theoretical values will therefore be used. Since the amount of energy involved in this output is relatively small, a slight deviation from the actual value will not affect significantly the overall mass and energy balance.

3.3 Heat source general arrangement

Several conceptual arrangements were studied and some modifications had to be made to our original proposal. To achieve the optimum utilisation of the heat sources, the actual hot well will have to be split. The condensate of the 3rd and 4th effect will be mixed with the water from the barometric legs of the steam ejectors in order to be used as a hotter heat source for the high temperature heat pump. The condensate of the 1st and 2nd effect will still be used as boiler-feed water. The surplus, however, will be mixed with the water used as heat source for the high temperature heat pump.

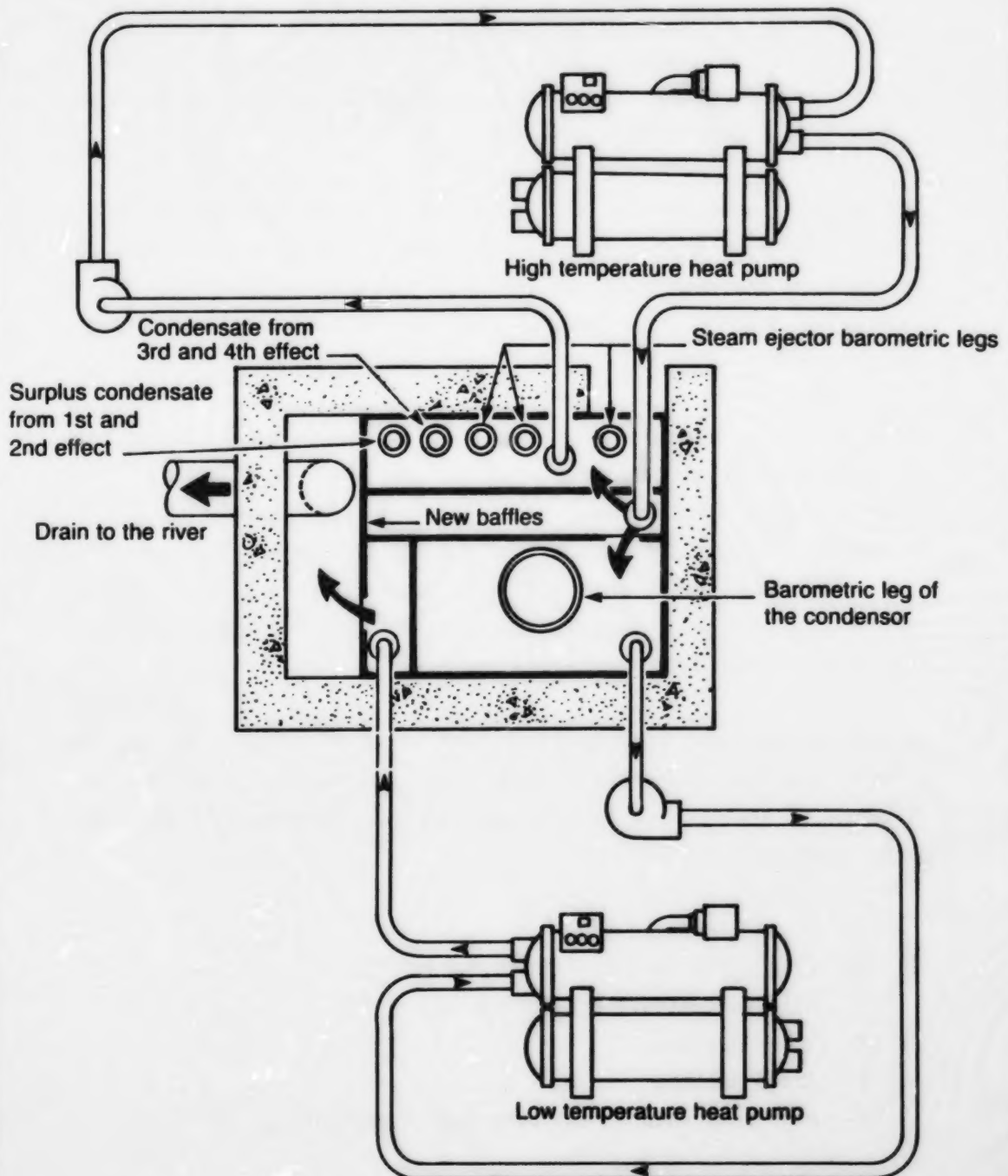


The remaining water, flowing from the barometer leg of the condenser, will be used as the heat source of the low temperature heat pump.

This arrangement is slightly different from our original proposal; this was required to maximize the return of investment required to implement this project.

Figure 3.3 shows the general flow diagram of the warm waste water at the hot well which is used as a heat source sump for the two heat pumps.

Figure 3.3 Warm waste water flow diagram at the hot well





4. LOW TEMPERATURE HEAT PUMP INSTALLATION

4.1 Low temperature heat requirements

The temperature level of the recovered heat use will dictate the output temperature of this heat pump.

The preheating of the air supply to the dryer will be the major use of the recovered heat. In order to reach a good balance between the low temperature heat pump and the high temperature heat pump, it is imperative that a large part of the energy needed for dryer supply air preheating be provided by the low temperature heat pump.

Several low temperature recovered heat uses have been studied, two of them need a temperature level of at least 60°C (140°F). In order to use a standard heat exchanger, the output temperature level of the low temperature heat pump should be set at 65°C (150°F). Preheating the dryer air supply at a temperature level of 60°C (140°F) will allow a good balance between the low temperature heat pump and the high temperature heat pump.

Including the heat of compression equivalent (energy input to the motor), the low temperature heat pump will supply 1 320 kW (4,5 MBTU/hr) to several low temperature heat requirements throughout the plant, such as:

- 1- Dryer air preheating
- 2- Evaporated can sterilizer preheating
- 3- Milk concentrate preheating
- 4- Water heating
- 5- Space heating
- 6- High temperature heat pump source preheating



We based our analysis on the standard product of one manufacturer. For the capacity involved, a McQuay Templifier, model T.P. 0-100 would be the best unit for the expected use. The energy input to the unit would be 277 kW with an expected C.O.P. of 4,65

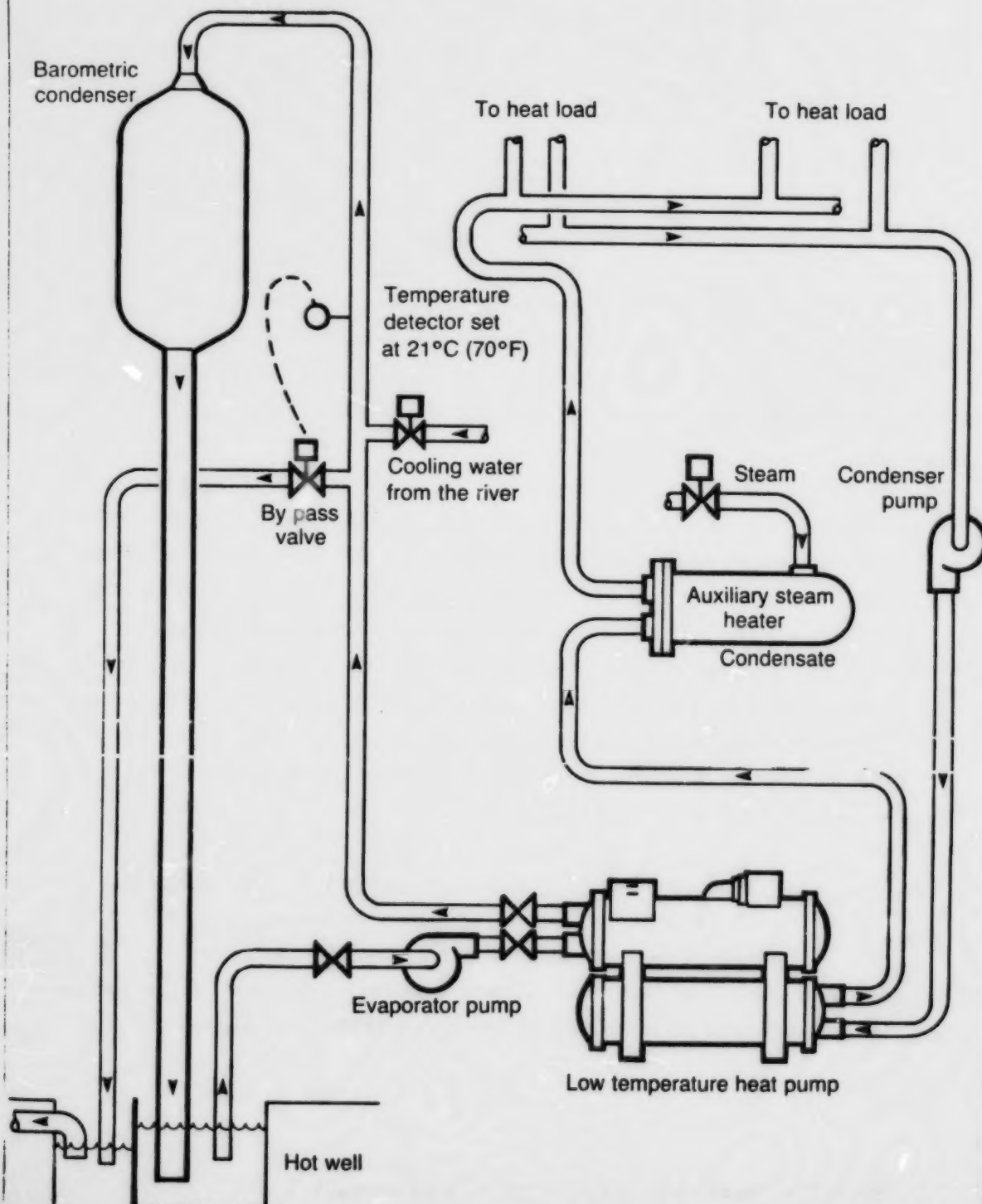
4.2 Description of the installation

The heat pump will be installed on a platform 4,8 m (16 feet) above the ground floor. This height will reduce the risk of water flooding during the cleaning operations and will also avoid interference with production traffic on the main floor.

On the evaporator side, 950 L/min (250 US GPM) will be circulated from the hot well by a centrifugal pump. The heat source will be the hot water 40°C (105°F) rejected from the barometric condenser. The heat source will be cooled from 40°C (105°F) down to 25°C (77°F). Once it has been cooled by the heat pump, the water will be used as cooling water for the barometric condenser. In order to reach the required low temperature level (21°C) at the inlet of the condenser, the actual fresh water from the river will be mixed with the cool water from the heat pump evaporator. The schematic of this arrangement is shown on Figure 4.1.

The water output of the heat pump evaporator will be flowed back to the hot well as soon as the inlet water temperature to the barometric condenser reaches the high temperature limit (21°C). This operation will be achieved with a modulating by-pass valve and a temperature sensor installed on the barometric inlet pipe.

Figure 4.1 Low temperature heat pump installation schematic





Because of a close loop circulation, the heat source will not be affected by the variations in the process water flow. A special arrangement of the hot well should be provided to eliminate the unnecessary cooling of the heat source by the cooled water return.

On the condenser side of the heat pump, a centrifugal pump will circulate 1 700 L/min. (450 US GPM) of 65°C (150°F) water in a primary circuit close loop recirculation arrangement as shown in 4.1. In order to achieve a steady state operation of the heating of the several utilisations, a shell and tube heat exchanger supplied with steam will be used. This heat exchanger will act as a fossil fuel heating apparatus when the heat pump will be stopped.

The modulation of the heat pump capacity will be achieved by a temperature detector installed on the return of the primary heating loop (input of the heat pump condenser).

The return temperature will increase if several heat utilisations are not in use as the supplied hot water is fed directly in the return of the primary heating loop.

The electrical supply of the heat pump and accessories will come from the main power room of the plant. The heat pump motor starter will be installed next to the main distribution adjacent to the new motor control center used for control for several pumps. Because of the dust and humidity build-up in the process area, all the motor starters are installed in the electrical room. Electrical feeder enclosed in rigid conduct will carry the electrical energy up to the site of utilisation. A provision for control wiring will be installed next to the main feeders.



4.3 Capital costs requirements

Low Temperature Heat Pump Installation (Labor, overhead and profit included)

Heat pump (McQuay Templifier TP 0-100)	115 000 \$
Site installation	15 000
Platform cost share	9 000
Electrical	
- Heat pump electrical supply	24 500
- Evaporator pump electrical supply	2 200
- Condenser pump electrical supply	2 500
Evaporator mechanical	
- Evaporator pump and accessories	5 700
- Piping and fitting	8 000
- Control system	6 300
- Flow meter gages and thermometers	3 800
- Actual equipment modification	7 000
Condenser Mechanical	
- Condenser pump and accessories	3 500
- Piping and fittings	13 300
- Steam heat exchanger	10 500
- Manometers and thermometers	2 700
Hot well modifications	5 000
Heat pump control	10 000
Start-up	5 000
Total installation cost:	249 000 \$

4.4 Profitability analysis

The economic profitability of the installation will be evaluated with the capital cost requirements for each waste heat recovery utilisation. The total capital cost of the heat pump will be distributed on a similar basis as the total energy is divided for different utilisations.

The major part of the installation cost should be assigned to the major energy user. This statement will be right if we assume that it is only the cost increases in an already spent total capital cost that should be assigned to an additionnal energy user.

We propose the following sharing out of the total capital cost:

MAIN ENERGY USER CAPITAL COST SHARE:

$0,5 \times \text{total capital cost} + \% \text{ of energy use} \times (0,5 \times \text{total capital cost})$

SECONDARY ENERGY USER CAPITAL COST SHARE:

$\% \text{ of energy use} \times (0,5 \times \text{total capital cost})$



Based on this assumption, the total capital cost should be distributed as follows:

Dryer air pre-heating

$$124\,500 \$ + \frac{2\,376}{4\,500} \times 124\,500 = 190\,200 \$$$

Concentrate pre-heating

$$\frac{326}{4\,500} \times 124\,500 \$ = 9\,000 \$$$

Heating of cleaning water

$$\frac{500}{4\,500} \times 124\,500 \$ = 13\,800 \$$$

High temperature heat pump
heat source share

$$\frac{1\,300}{4\,500} \times 124\,500 \$ = 36\,000 \$$$

Total cost: 249 000 \$

Space heating

(No contribution to the heat pump capacity increase, this utilisation will use the excess heat only)

Can sterilizer pre-heating

(Because of a too low utilisation factor, this energy usage is not recommended)



5. HIGH TEMPERATURE HEAT PUMP INSTALLATION

5.1 High temperature heat requirements

In a milk transformation plant, several processes require an energy supply at a temperature just below the water boiling point. An accurate survey of the temperature level of the energy supply to several different processes showed that a 93°C (200°F) temperature output would lead to the maximum utilisation of the recovered heat.

Such a temperature level can be reached with a single stage heat pump only if the heat source available is at a temperature level high enough to avoid excessive pressure differentials between the compressor inlet and outlet. In our case, the heat source leaving the evaporator should not be below 43°C (110°F) if the condenser output temperature is maintained at 93°C (200°F).

To offset the unsufficient amount of high temperature heat source, a part of the energy supply to the high temperature heat pump will be produced by the low temperature heat pump.

Because of the overall low C.O.P. of a cascade heat pump installation, all the available high temperature recoverable waste heat will have to be separated from the low temperature heat sources.

Modifications of the hotwell and added new waste heat sources will supply approximately half of the energy input to the high temperature heat pump. The remainder will be provided by the low temperature heat pump.

Including the heat of compression equivalent (energy input to the compressor motor) the high temperature heat pump will supply 840 kW (2 870 000 BTU/hr) to the following high temperature uses of the plant. These are:

- 1- Dryer air preheating
- 2- Evaporated can sterilizer preheating
- 3- Whole milk pasteurizer preheating
- 4- Cream pasteurization
- 5- Boiler feed water preheating

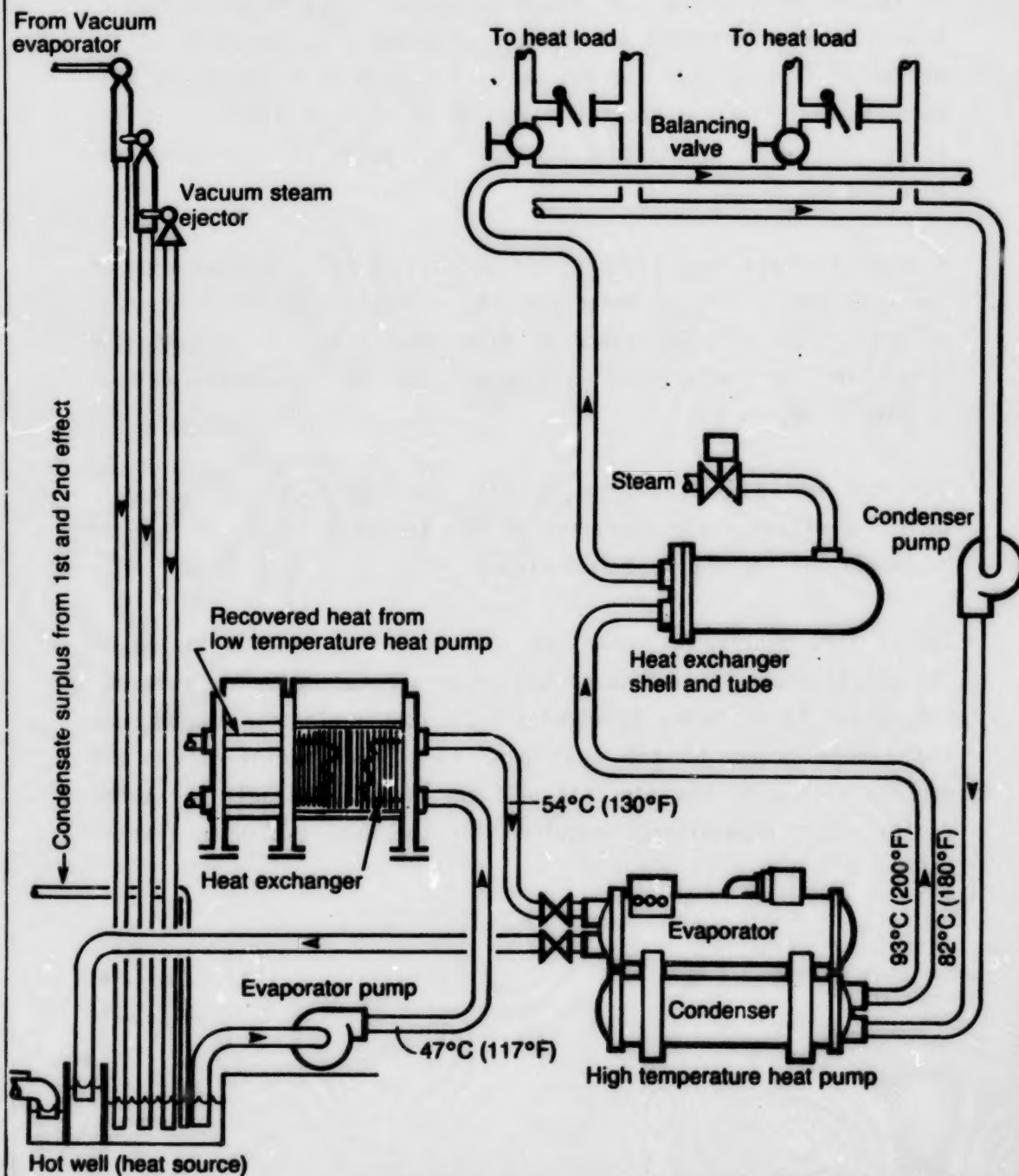
The standard product of a manufacturer which will fit the required needs will be a McQuay Templifier model T.P.-063. The energy input of the compressor will be 252 kW with an expected C.O.P. of 3,46.

5.2 Description of the installation

The high temperature heat pump will be installed next to the other heat pump on the same platform 4,8 m (16 feet) above the ground floor. This height will reduce the risk of water damage during cleaning operations and will also avoid interference with production traffic on the main floor.

A 760 L/min (200 US GPM) centrifugal pump will assure a continuous flow in the evaporator of the heat pump. Because of the insufficient hot water source, the cooled water leaving the evaporator will return in the hotwell section next to the suction side of the pump. This set-up will allow a partial mix of cooled water at 43°C (110°F) with the available hot water sources at higher temperatures. This method will insure adequate water supply to the centrifugal pump. The required inlet temperature at the evaporator will be obtained with the use of a heat exchanger installed between the pump and the heat pump as shown in figure 5.1

Figure 5.1 High temperature heat pump installation schematic





The excess cooled water will exit the evaporator at a temperature of 43°C (110°F) and will be drained in the low temperature hot well to recover another part of its heat content. The proposed evaporator supply arrangement will not be affected by a variation of the hot water flowing into the hot well. As in the low temperature heat pump installation, a special modification will be required at the actual hot well arrangement to avoid the water to drop below the pump suction inlet.

A primary closed loop circuit will be used on the condenser side of the heat pump. The condenser pump will circulate 1 100 L/min. (287 US GPM) which will be heated to 93°C (200°F) inside the condenser tubes. This hot water heating loop will deliver the recovered heat to several processes.

When the heat pump is stopped, a shell and tubes heat exchanger will permit a steady state operation of all the heat loads. This heat exchanger will be supplied with steam.

Fossil fuel heating is essential to achieve the maximum saving on the actual electric heating of the dryer air supply. This particular option is necessary to eliminate the costly electric demand peak that could occur if the heat pump is stopped momentarily. The monthly saving on the electric bill can offset by itself the total capital cost expenditures required for the heat exchanger installation.



The modulation of the heat pump will be achieved by a temperature detector installed on the primary heating loop return line. The secondary loop installed on each heating utilisation will lower the water temperature to a predetermined temperature level. When one of the secondary heating process will not be in operation, the water supply will be by-passed directly into the return of the primary circuit. The temperature detector installed on the return pipe will sense this temperature increase immediately and it will automatically modulate the load on the heat pump in order to maintain the predetermined output temperature.

Similarly to the low temperature heat pump installation, the electrical supply of this second heat pump will come from the main power-room of the plant. The heat pump motor starter will be installed next to the main distribution panels. Electrical wiring enclosed in rigid conduits will feed the electricity to the site of utilisation. The control wiring will be installed in a rigid conduit next to the main feeders.

5.3 Capital cost requirements

High Temperature Heat Pump Installation

(Labor, overhead and profit included)

Heat pump (McQuay Templifier T.P. 0-063)	85 000 \$
Site installation	15 000
Part of the platform cost	9 000
Electrical	
- Heat pump electrical supply	22 000
- Evaporator pump electrical supply	2 000
- Condenser pump electrical supply	2 500
Mechanical installation for the evaporator	
- Evaporator pump and accessories	5 000
- Piping and fittings	7 900
- Flow meter gages and thermometers	3 800
- Actual piping modification	6 000
- Control system	5 000
Mechanical installation for the condenser	
- Condenser pump and accessories	4 000
- Piping and fittings	12 400
- Steam heat exchanger	11 200
- Manometers and thermometers	3 000
Hot well modifications	5 000
Heat pump control	10 000
Start-up	5 000
Heat exchanger and secondary circuit for the cascade operation	33 200
Total installation cost:	247 000 \$



5.4 Profitability analysis

In order to achieve a more accurate evaluation of the expected profitability of the installation, the cost of the heat exchanger used for a partial cascade should be included in the total installation cost of the high temperature heat pump. Since each high temperature heat load will have a different profitability, the economic evaluation of the installation should be made on a step by step basis. The total capital cost of the heat pump installation will be shared on a similar basis as the energy is divided for different utilisations.

We propose the same capital cost distribution as the one used for the low temperature heat pump.

Total cost of the high heat pump installation:	247 000 \$
Share of the low heat pump installation cost:	<u>36 000</u>
Total capital cost to be shared:	283 000 \$



Based on our original assumption shown on page 25, the total capital cost should be distributed as follows:

Dryer air pre-heating

$$141\,500 \$ + \frac{1\,980}{2\,870} \times 141\,500 = 239\,100 \$$$

Cream pasteurization

$$\frac{290}{2\,870} \times 141\,500 \$ = 14\,300 \$$$

Boiler feed water preheating

29 600 \$

Total cost:

283 000 \$

Can sterilizer preheating

(This process has a very low utilisation factor, therefore, the expected savings are low and will not justify the investment)

Pasteurization preheating

(This process has a very low utilisation factor, therefore, the expected savings are low and will not justify the investment)



6.0 LOW TEMPERATURE RECOVERED HEAT USE

6.1 Dryer supply air preheating

6.1.1 General

The powder milk production is one of the most used processes of this transformation plant. Based on the past, we expect the milk dryer to operate about 5 100 hrs/year. It will be considered as the main user of the recovered heat.

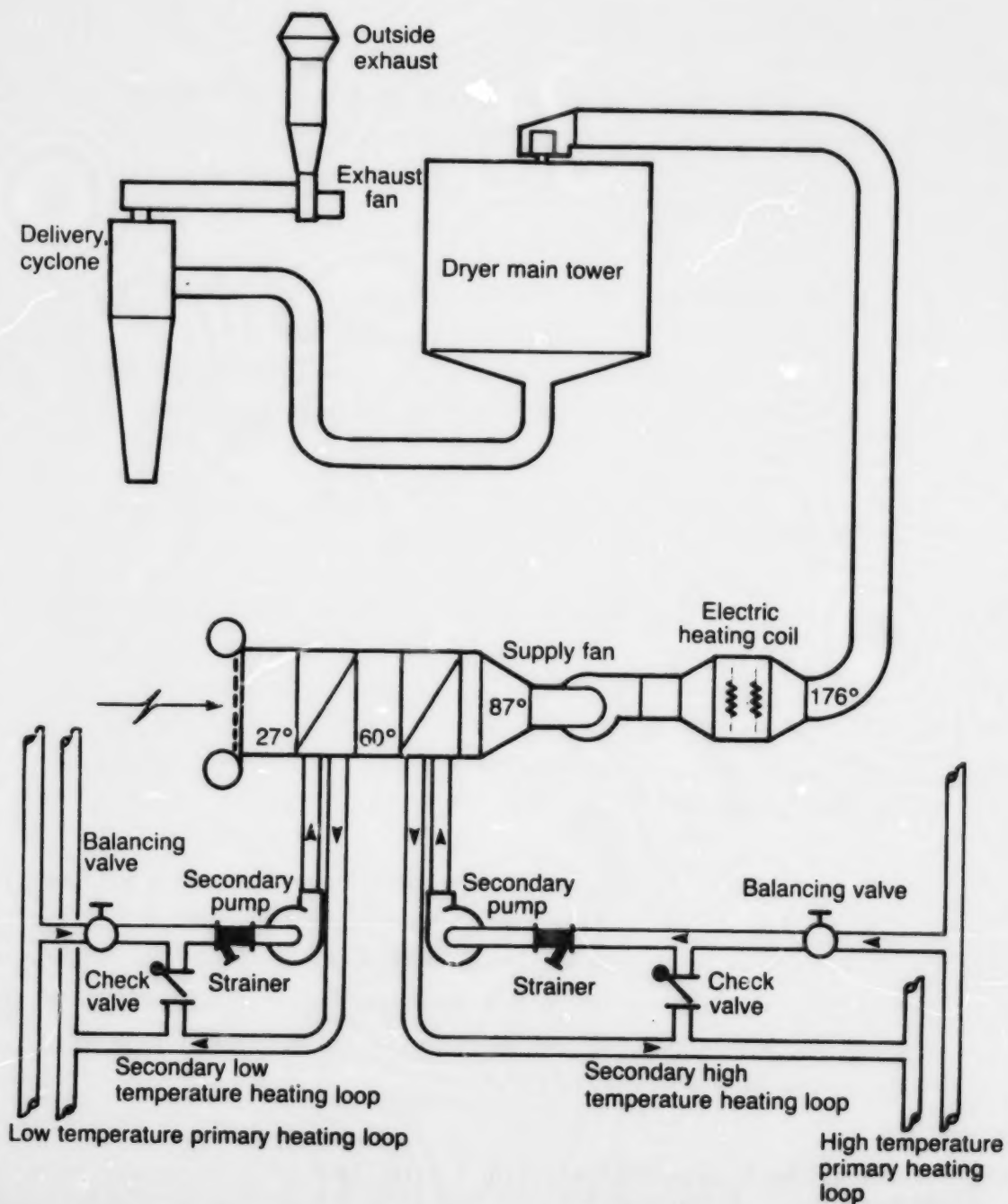
With a low temperature heat pump installation, the availability of recovered heat at a 65°C (150°F) temperature level will be used for the dryer air preheating. An oversized heating coil can preheat inlet air temperature up to 60°C (140°F) with a water temperature inlet of 65°C.

6.1.2 Description of the installation

A six row heating coil will be installed in the inlet plenum of the fan intake just after the air filter. The air pressure drop across the coil will be easily offset by the actual fan capability. No control system will be used for capacity modulation of the heating coil. The maximum preheating should always be possible during the steady state operation of the dryer.

The water flow will be regulated by a balancing valve which will be calibrated for the exact flow needed for the heating purpose. Flow meter will be used to achieve an accurate calibration. The water supply will be either drawn by the secondary heating loop pump to be fed in the preheating coil or it will be returned in the primary heating loop as shown in figure 6.1.

Figure 6.1 Dryer air preheating schematic





6.1.3 Capital cost of the installation

DRYER AIR SUPPLY PREHEATING
(Installation labor included)

Heating coil	14 000 \$
Piping and accessories	11 000
Secondary pump and accessories	5 000
Pump electrical supply	2 000
Flow meter and calibration	2 000
Thermometers and monometers	2 500
Sub total:	36 500
Administration: 15 %	5 500
Profit: 10 %	4 100
Total capital cost:	46 500 \$



6.1.4 Profitability analysis

i- Capital cost requirements

- Share of the heat pump installation cost	190 000 \$
- Preheating capital cost	46 500
Total capital cost:	236 700 \$

ii- Expected energy savings

- Actual energy cost (electricity)	3,5 ¢/kWh
- Recovered energy cost (electricity)	0,78¢/kWh

Unitary saving:	2,72¢/kWh
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- Preheating cool capacity:	696 kW
- Expected hourly energy saving:	18,94 \$
- Operating hours of the equipment:	5 100 hours

- Expected yearly saving:	96 594 \$
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iii- Return on investment

- Simple payback period:

$$\frac{236\,700\ \$}{96\,594\ \$} = 2,45\ \text{years}$$

6.2 Can Sterilizer preheating

6.2.1 General

The plant owner diversified his commercial product recently. A new evaporated milk canning department had been added to the original transformation plant.

Despite an expected low profitability of any improvement of the overall efficiency of this production line caused by a light utilisation of the equipment, we made an evaluation of the possible recovered heat utilisation in this department in case of a drastic change in the commercial market. Actually, when the evaporated milk production is in operation, the dry milk powder production is stopped.

The identified possible recovered heat usage will be for the can preheating before they enter in the sterilizer. The cans and their content have to be heated from 10°C (51°F) up to 90°C (195°F). The actual steam preheating could be modified to include a hot water close loop heating system.

It should be noted that the cans need to be cooled after the sterilisation process. Because of possible contamination problems, this available heat source will be indirectly recovered by a heat exchanger before being cooled by the heat pump.

6.2.2 Description of the installation

A buffer tank will be installed at the can preheater outlet. An auxiliary pump will draw up the water leaving the preheater and will circulate it in a triple stage heat exchanger before it will be supplied to the preheater inlet.

The heat source of the first stage of the exchanger will be provided by the low temperature heat pump heating loop. The heat source of the second stage will be the can cooling water outlet. The heat source of the third stage of the exchanger is the high temperature heat pump heating loop.

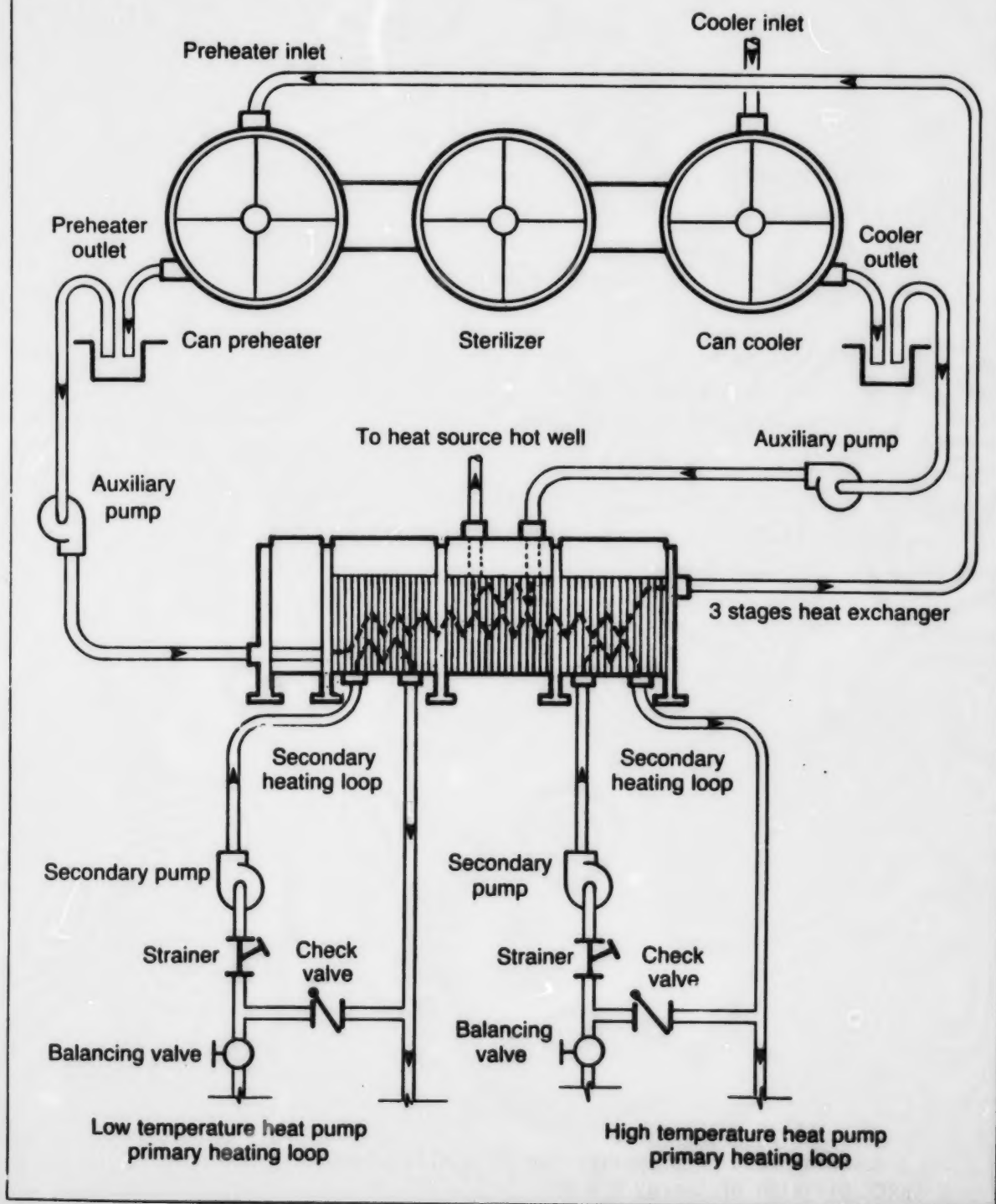
On each stage, no control system will be used for capacity modulation of the heat exchanger. The maximum heat use is always required.

The water flow will be regulated by a balancing valve which will be calibrated for the exact water heating flow required. Flow meters will be used to achieve an accurate calibration.

The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be directly by-passed in the primary loop return.

The flow diagram of this installation is shown on figure 6.2.

Figure 6.2 Can preheating system schematic





6.2.3 Capital cost of the installation

CAN STERILIZER PREHEATING (Installation labor included)

Heat exchanger	19 000 \$
Piping and accessories	7 500
Secondary pump	3 500
Share of the auxiliary pumping installation	10 500
Secondary pump	
- Electrical supply	2 000
Flow meters and calibration	1 400
Thermometers and pressure gages	2 500
Sub total:	46 400
Administration: 15 %	7 000
Profit: 10 %	5 100
Total capital cost:	58 500 \$

6.2.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	- 0 -
- Preheating capital cost	58 500

ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
- Recovered energy cost (electricity)	0,78¢/kWh
Unitary saving	1,78¢/kWh
- Heat exchanger capacity:	351 kW
- Expected hourly energy saving:	6,24 \$
- Operating hours:	1 000 hours
- Expected yearly saving:	6 240 \$

iii- Return on investment

- Simple payback period:	$\frac{58\,500 \$}{6\,240 \$} = 9,4 \text{ years}$
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6.3 Concentrate preheating

6.3.1 General

The different milk concentrates require reheating before the final transformation. Actually, a shell and tube heat exchanger is used for this particular process. The energy supply comes from steam condensation under a vacuum environment to match the right temperature level.

Based on the information received from the plant personnel, a hot water heating system has more accurate heat control than steam heating for this particular process. The actual problem is the possible cooking of the concentrate with live steam in the exchanger. Furthermore, a plate type heat exchanger would be suitable for hot water and would replace the actual shell and tube exchanger.

6.3.2 Description of the installation

A plate type heat exchanger will be installed for concentrate preheating. The milk pump could easily offset the pressure drop inside the heat exchanger.

A secondary heating loop will be used for the energy supply to the heat exchanger. Modulation of the heating capacity will be achieved by a three-way control valve installed on the secondary heating loop as shown on figure 6.3. This arrangement will permit a close control of the concentrate outlet temperature.



A balancing valve installed on the secondary heating loop will be used to regulate the maximum flow inside the heat exchanger. Flow meters will be used to achieve an accurate calibration. The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be by-passed and returned in the primary loop.

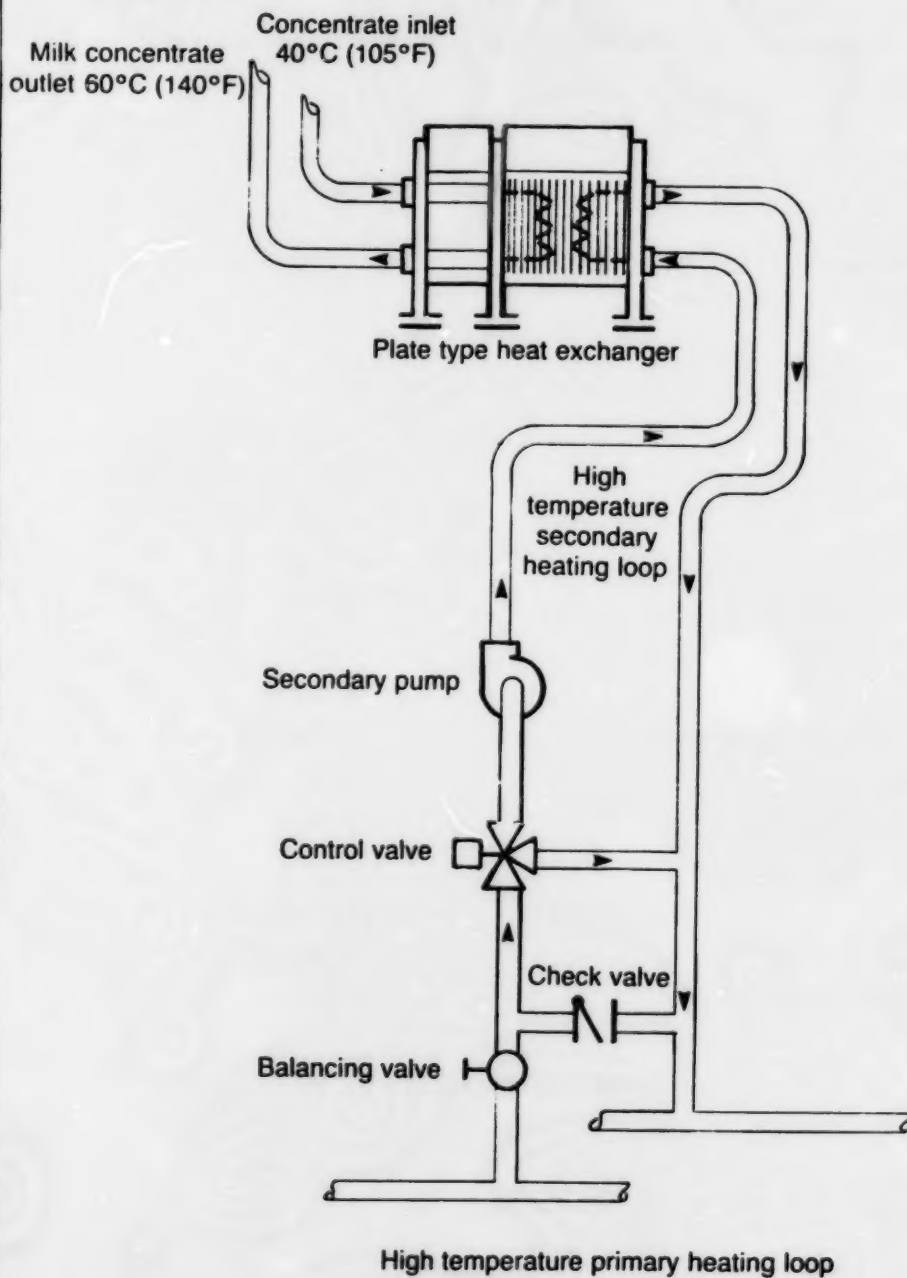
6.3.3 Capital cost of the installation

CONCENTRATE REHEATING

(Installation labor included)

Heat exchanger	6 500 \$
Secondary pump	2 200
Pump electrical supply	2 000
Piping and accessories	2 800
Flow meter	1 200
Thermometers and pressure gages	2 000
Control system	6 000
Milk piping modification	2 000
Sub total:	24 700
Administration: 15 %	3 700
Profit: 10 %	2 800
Total capital cost:	31 200 \$

Figure 6.3 Milk concentrate reheating schematic



6.3.4 Profitability analyses

i- Capital cost

- Share of the heat pump installation	9 000 \$
- Concentrate heating	31 200

Total capital cost:	<u>40 200 \$</u>
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ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
---	-----------

- Recovered energy cost (electricity)	0,78¢/kWh
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Unitary saving	<u>1,78¢/kWh</u>
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- Heat exchanger capacity:	102 kW
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- Expected hourly energy saving:	1,82 \$
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- Operating hours:	6 000 hours
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- Expected yearly saving:	10 920 \$
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iii- Return on investment

- Simple payback period:

$$\frac{40\,200 \$}{10\,920 \$} = 3,66 \text{ years}$$

6.4 Cleaning water heating

6.4.1 General

A tremendous amount of hot water is used for cleaning purposes throughout the milk transformation plant. The preliminary evaluation of the hot water usage indicated that approximately 70 000 L (15 000 gallons) are used daily.

Actually the cleaning water heating is accomplished at the point of delivery. A special mixing valve is used to heat the fresh water by direct steam injection. Several problems are associated to this type of water heating:

- No hot water gun can be used
- The hot water temperature control is not accurate
- Frequent injuries have resulted from a bad adjustment of the hot water temperature.

The installation of a hot water storage tank and its distribution system will not only provide substantial energy savings but will also reduce most of the afore mentioned problems.

6.4.2 Description of the installation

A vertical water reservoir will be installed next to the heat pump location. An auxiliary pump will draw cool water from the bottom of the storage tank, will feed it through a plate type heat exchanger where the water is heated up to 60°C (140°F). The water will then be returned to the top of the reservoir.

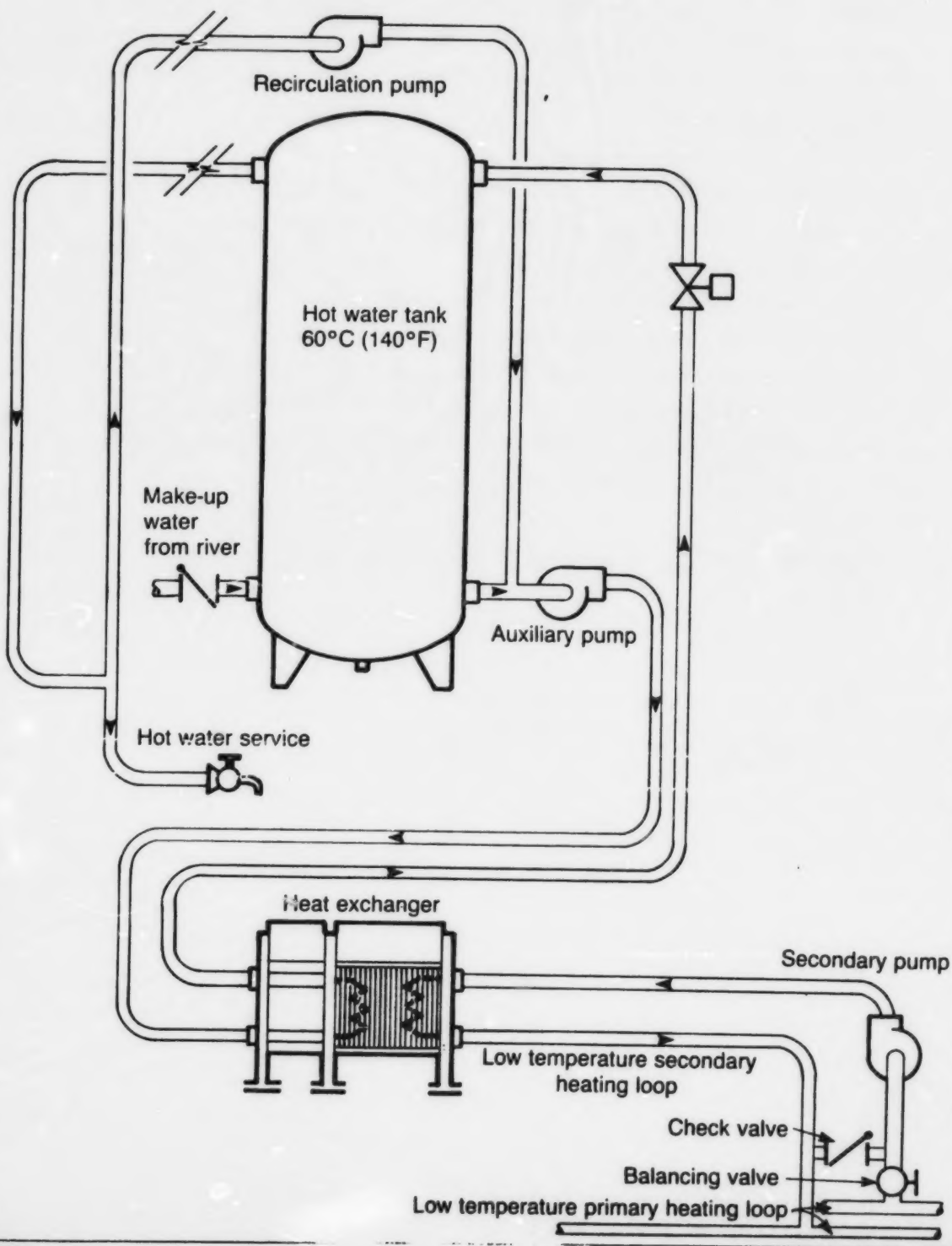


Variation of the incoming water temperature will be offset by flow modulation through the heat exchanger. This control system will assure a constant hot water supply temperature at the top of the reservoir. This arrangement will maximize the buffer capability of the hot water reservoir.

A secondary heating loop will be used for energy supply to the heat exchanger. Modulation of the heat exchanger capacity will be achieved on the heated side only. The water flow in the secondary piping will be regulated by a balancing valve calibrated for the exact heating flow requirement. Flow meters will be used for accurate calibration. The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be directly by-passed in the primary loop return. The schematic of this installation is shown on figure 6.4.

A new distribution network will be used to supply hot water to each point of use.

Figure 6.4 Hot water preheating schematic





6.4.3 Capital cost of the installation

CLEANING WATER HEATING (Installation labor included)

Hot water reservoir	28 000 \$
Heat exchanger	12 000
Auxiliary pump	1 900
Secondary heating loop pump	1 900
Control system (valve and accessories)	5 000
Pump electrical supply	4 000
Piping (heating side)	11 000
Hot water distribution piping	15 000
Recirculation pumps	500
Insulation	6 000
Flow meter and calibration	1 500
Thermometers and pressure gages	2 000
Sub total:	88 800
Administration: 15 %	13 200
Profit: 10 %	10 000
Total capital cost:	112 000 \$

6.4.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation cost	13 800 \$
- Hot water heating equipment	112 000
Total capital cost:	125 800 \$

ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
- Recovered energy cost	0,78¢/kWh
Unitary saving:	1,78¢/kWh
- Heat exchanger capacity:	146 kW
- Expected hourly energy saving:	2,60 \$
- Count of equivalent hours: (operation)	7 500 hours

- Expected yearly saving:	19 500 \$
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iii- Return on investment

- Simple payback period:

$$\frac{125\,800\ \$}{19\,500\ \$} = 6,45\ \text{years}$$



6.5 Space heating

6.5.1 General

The transformed milk as well as empty cans are stocked in several large storage areas. A part of the warehouses is also used for packaging and pelletizing of goods. Because of the nature of the space usage, or the process involved, no internal heat gain offsets the wall and roof heat losses. The heating load of the storage room is also increased by the infiltration heat losses when the large openings of the receiving and shipping area are opened.

Because of the always increasing dimensions of the milk trucks, the large openings of the receiving area are often left opened when the trucks are unloaded. This situation increases the heating load of the building.

At the present time, electricity is the sole energy source for space heating in this plant. The high unitary cost of electric heating makes the hydronic space heating with recovered heat very attractive.

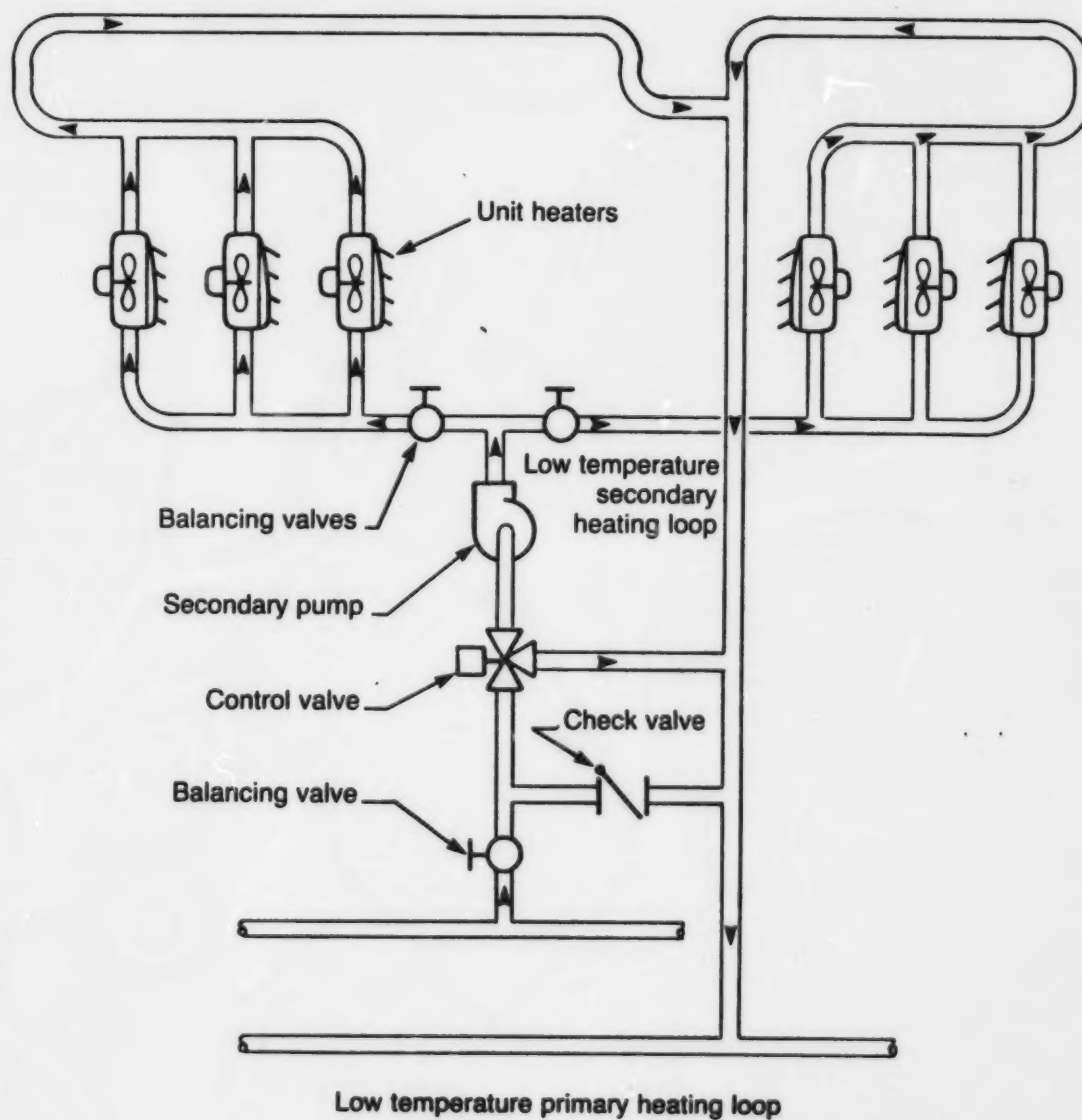


6.5.2 Description of the installation

Secondary heating loops will be used to supply warm water to the proposed unit heaters installed in the storage and in the receiving areas. These unit heaters will be designed for a low temperature hot water supply. The location of these units will be based on the particular heating loads of the building.

A three-way valve will be used to modulate the hot water temperature. The water flow in the secondary loop will be regulated by a balancing valve calibrated for the exact heating flow requirements. Flow meters will be used for accurate calibration. The hot water supply will either be pumped in the secondary heating loop or it will be by-passed and returned to the primary loop as shown in figure 6.5.

Figure 6.5 Space heating system schematic





6.5.3 Capital cost of the installation

SPACE HEATING

(Installation labor included)

Unit heaters	21 000 \$
Piping and accessories	16 300
Secondary pump	2 200
Pump electrical supply	2 000
Unit heaters electrical supply	5 000
Control valve and accessories	4 500
Unit heaters control accessories	2 000
Flow meters	2 000
Thermometers and pressure gages	1 000
Sub total:	56 000
Administration: 15 %	8 000
Profit: 10 %	6 000
Total capital cost:	70 000 \$

6.5.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation cost	- 0 -
- Space heating system	70 000

ii- Expected energy savings

- Actual energy cost (electric heating)	4,5 ¢/kWh
- Recovered energy cost	0,78¢/kWh
Unitary saving:	3,72¢/kWh
- Total heating load:	200 kW
- Expected hourly energy saving:	7,44 \$
- Count of equivalent full heating load hours	2 600 hours

- Expected yearly saving:	19 350 \$
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iii- Return on investment

- Simple payback period:

$$\frac{70\ 800\ \$}{19\ 350\ \$} = 3,6\ \text{years}$$

7. HIGH TEMPERATURE RECOVERED ENERGY USAGE

7.1 Dryer supply air preheater

7.1.1 General

As with the low temperature heat pump, the dryer air supply preheating will also be considered as the main user of the recovered heat by the high temperature heat pump. With a 5 100 hour operation, this recovered energy user can more than offset the capital cost of the entire high temperature heat pump installation.

The availability of recovered heat at a 93°C (200°F) temperature level is the best opportunity to provide additional preheating of the dryer air supply. With an oversized heating coil, the air temperature could be heated to a temperature level as high as 88°C (190°F) with a water temperature of 93°C (200 °F) at the inlet of the coil.

7.1.2 Description of the installation

Adjacent to the first preheating coil, a six row heating coil will be installed at the inlet of the supply fan intake. The fan capability can easily offset the pressure drop across this additional heating coil.

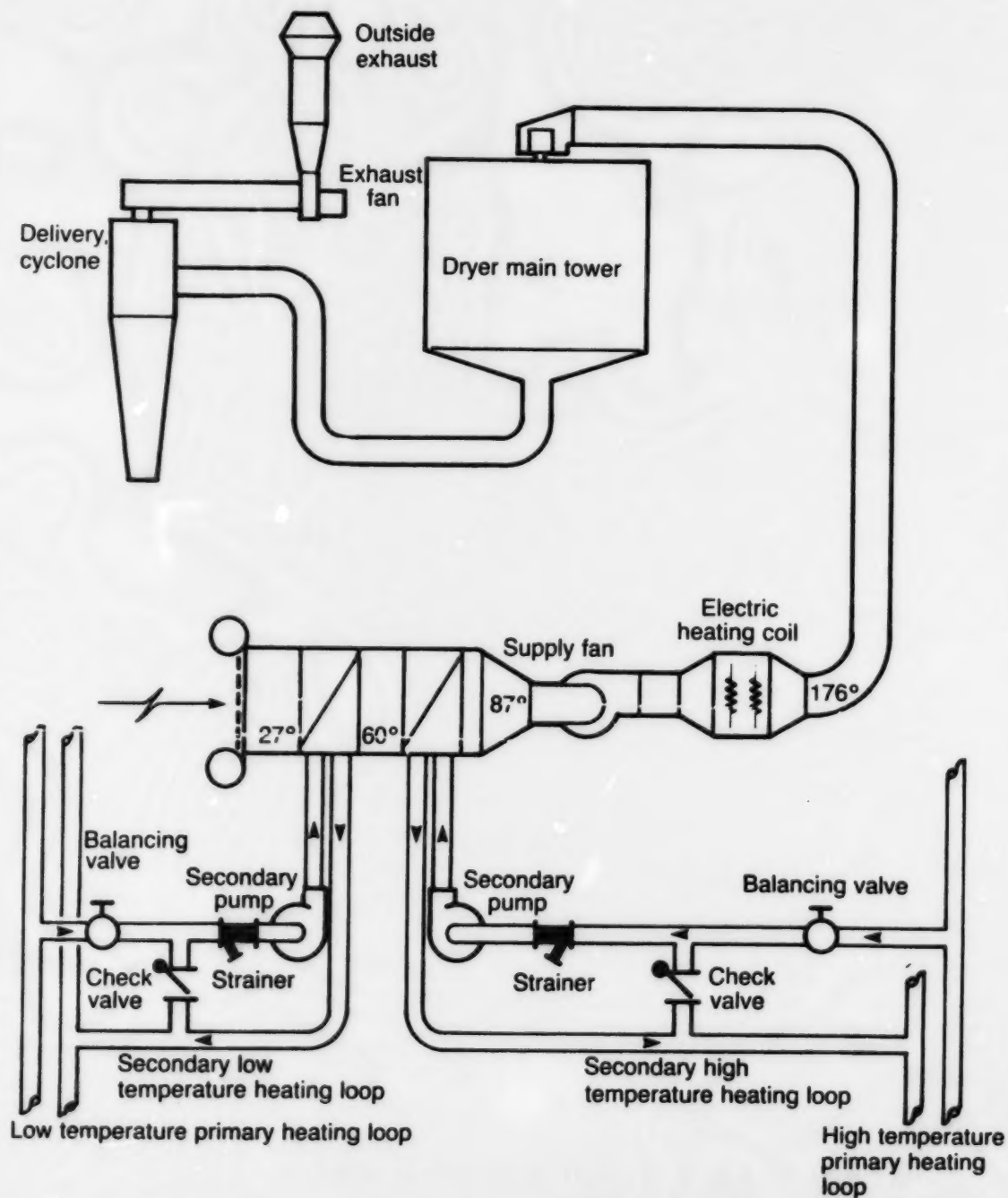
Because the maximum available heat should always be used, no control system will be required for capacity modulation of the heating coil. A balancing valve will regulate the flow of hot water to the exact quantity needed for the heating purpose. Flow meters will be used to achieve an accurate calibration. The hot water supply will either be pumped in the heating coil by a secondary loop circulation pump or it will be by-passed back into the primary loop return. The schematic of this installation is shown on figure 7.1.

7.1.3 Capital cost of the installation

DRYER AIR SUPPLY PREHEATING (Installation labor included)

Unit coil	14 000 \$
Piping and accessories	13 900
Secondary pumps and accessories	2 500
Pump electrical supply	2 000
Flow meters and calibration	2 000
Thermometers and pressure gages	2 500
Thermal Insulation	1 200
Sub total:	38 100
Administration: 15 %	5 700
Profit: 10 %	4 400
Total capital cost:	48 200 \$

Figure 7.1 Dryer air preheating schematic





7.1.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	239 100 \$
- Preheating capital cost	48 200
Total capital cost:	287,300 \$

ii- Expected energy savings

- Actual energy cost (electricity)	3,56¢/kWh
- Recovered energy cost	1,17¢/kWh
Unitary saving:	2,39¢/kWh
- Preheating coil capacity:	580 kW
- Expected hourly energy saving:	13,51 \$
- Operating hours of the equipment	5 100 hours
- Expected yearly saving:	68 920 \$

iii- Return on investment

- Simple payback period:

$$\frac{287\ 300\ \$}{68\ 920\ \$} = 4,17\ \text{years}$$

7.2 Can sterilizer preheating

7.2.1 General

Similar to the low temperature heat pump installation, the availability of high temperature water from the second heat pump is adequate to complete the can preheating at the sterilizer. The same discussion previously presented with the low temperature recovered energy usage could be applicable for this case.

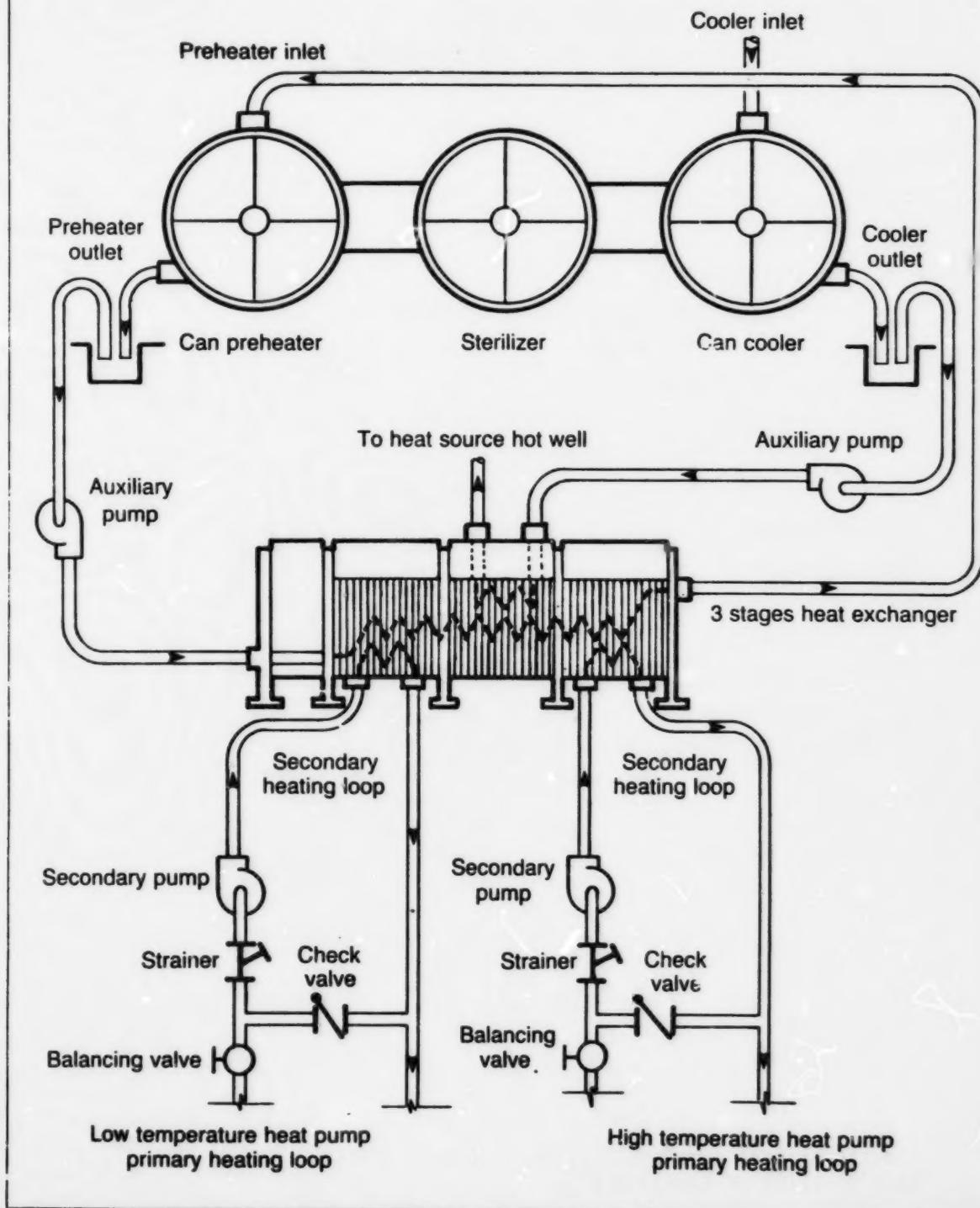
7.2.2 Description of the installation

The final preheating will be achieved in the third section of the triple stage preheat exchanger as shown in figure 7.2.

Similarly as with the low temperature installation, no control will be used for capacity modulation of the heat exchanger. The maximum heat recovery is always required.

The primary and secondary loop arrangement including all the accessories will be similar as for the low temperature recovered heat use.

Figure 7.2 Can preheating system schematic





7.2.3 Capital cost of the installation

CAN STERILIZER PREHEATING (Installation labor included)

Heat exchanger	18 500 \$
Piping and accessories	7 500
Secondary pump	3 500
Pump electrical supply	2 000
Share of the auxiliary pumping installation	10 500
Flow meters and calibration	1 500
Thermometer and pressure gages	2 500
Piping insulation	800
Sub total:	46 800
Administration: 15 %	6 800
Profit: 10 %	5 400
Total capital cost:	59 000 \$



7.2.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	- 0 -
- Prehating capital capital cost	59 000
Total capital cost:	<u>59 000 \$</u>

ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
- Recovered energy cost	1,17¢/kWh
Unitary saving	<u>1,39¢/kWh</u>
- Heat exchanger capacity:	322 kW
- Expected hourly energy saving:	4,48 \$
- Operating hours:	1 000 hours
- Expected yearly saving:	4 480 \$

iii- Return on investment

- Simple payback period:	
	$\frac{59\ 000\ \$}{4\ 480\ \$} = 13,25\ \text{years}$

7.3 Whole milk preheating

7.3.1 General

Despite the fact that evaporated milk is produced by the same process as the skim milk concentrate, because of a lower total solids content, the vacuum type evaporator does not operate on the same basis. Due to the evaporator construction itself, the whole milk is partly preheated in each of the four effect heads. With evaporated milk, the total amount of energy exchange is not the same as with the skim milk concentrate.

An additional heat exchanger is used to preheat the flow of whole milk from 71°C (160°F) to 85°C (185°F). The total heat exchange is equivalent to 230 kW (1 125 000 BTU/hr). Fossil fuel generated steam is presently used as energy source for this heat exchanger.

When the process flow is changed from powder milk production to evaporated milk production, the main recovered energy user (preheating of the dryer) will be stopped. The whole milk preheating for evaporated milk production could be used to replace a part of the recovered energy use for the dryer operation. When it will be stopped, the high temperature heat pump will also be stopped if the total of the remaining recovered energy utilisations is less than 40 per cent of the heat pump capability.

7.3.2 Description of the installation

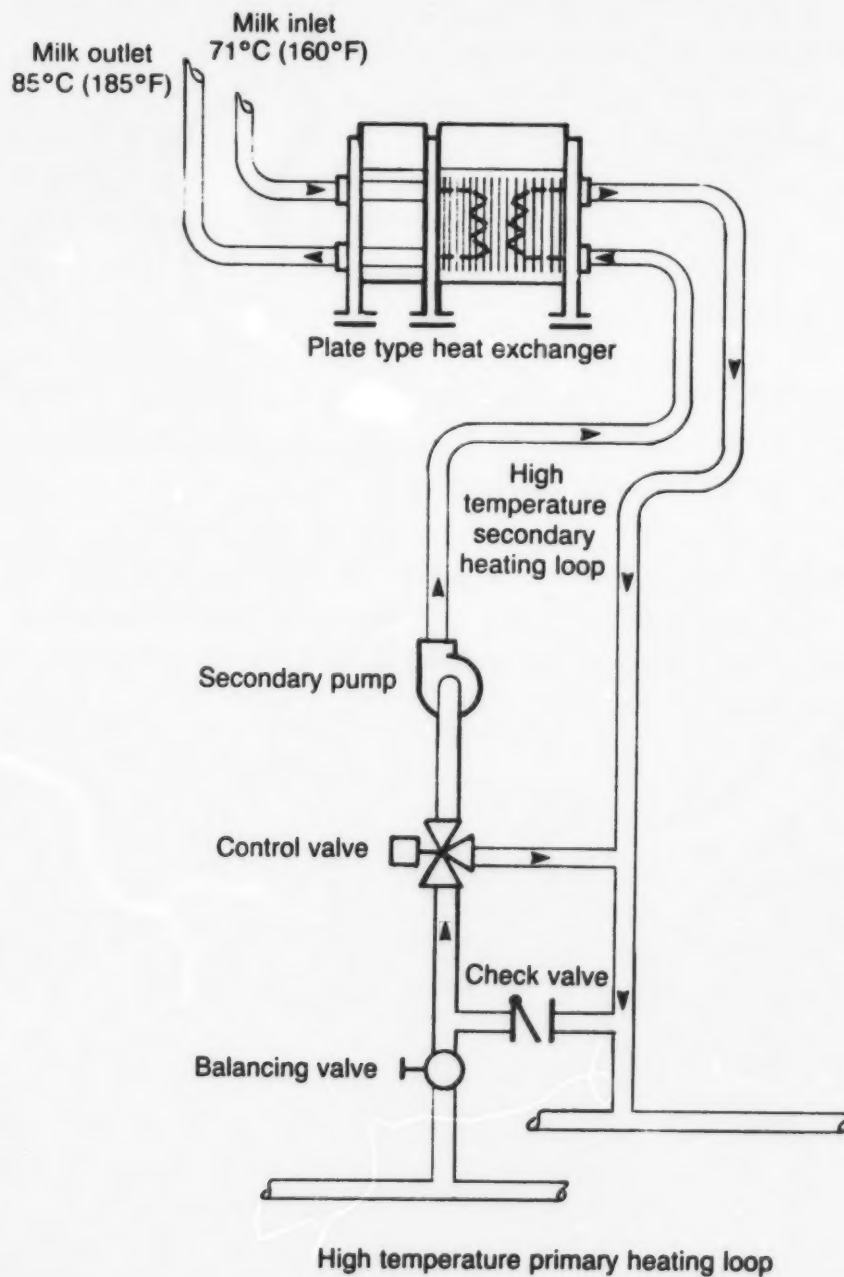
Next to the evaporator, a plate type heat exchanger will be installed for whole milk preheating. The actual milk pump could easily offset the pressure drop inside the heat exchanger.

A secondary heating loop will be used for the energy supply to the heat exchanger. Modulation of the heating capacity will be achieved by a three-way control valve installed on the secondary heating loop. This arrangement will permit a close control of the whole milk outlet temperature.

The hot water flow will be regulated by a balancing valve which will be calibrated for the exact heating flow required. Flow meters will be used to achieve an accurate calibration.

The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be directly by-passed in the primary loop return. The schematic of this installation is shown on figure 7.3.

Figure 7.3 Whole milk preheating schematic





7.3.3 Capital cost of the installation

WHOLE MILK PREHEATING (Installation labor included)

Heat exchanger	20 900 \$
Secondary pump	2 500
Pump electrical supply	2 000
Hot water piping	5 700
Milk piping	4 000
Control valve and accessories	5 000
Flow meters and calibration	1 500
Thermometers and pressure gages	2 500
Piping insulation	500
Sub total:	44 600
Administration: 15 %	6 700
Profit: 10 %	5 000
Total capital cost:	56 300 \$



7.3.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	- 0 -
- Whole milk preheating system	56 300
Total capital cost:	56 300 \$

ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
- Recovered energy cost	1,17¢/kWh
Unitary saving	1,39¢/kWh

- Heat exchanger capacity:	370 kW
- Expected hourly energy saving:	5,14 \$
- Operating hours:	1 000 hours
- Expected yearly saving:	5 140 \$

iii- Return on investment

- Simple payback period:

$$\frac{56\,300\ \$}{5\,140\ \$} = 11\ \text{years}$$



7.4 Cream Pasteurization

7.4.1 General

The pasteurization process is achieved by a rapid temperature rise of the product followed by cooling. Cream pasteurization is being done immediately after the cream is separated from the whole milk.

A 70 per cent regeneration is achieved in the heat exchanger used for cream pasteurization. Despite this high efficiency, a substantial amount of heat must be supplied to the pasteurizer. In order to achieve a close control of the pasteurization temperature, a hot water secondary loop is actually used. This secondary loop is heated by a shell and tube exchanger fed by fossil fuel generated steam.

The hot water available from the high temperature heat pump is at the right temperature required for the cream pasteurization. The secondary loop is already in place and the shift to the new energy source will not be expensive.

7.4.2 Description of the installation

The existing secondary loop will be connected to the primary heating loop of the high temperature heat pump. Modulation of the heating capacity will be achieved by a three-way control valve installed on the secondary heating loop. The arrangement will permit a close control of the cream pasteurization temperature.



A balancing valve installed on the secondary heating loop will be used to regulate the flow inside the heat exchanger. Flow meters will be used to achieve an accurate calibration. The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be by-passed into the primary loop return pipe. Figure 7.4 shows a schematic of this installation.

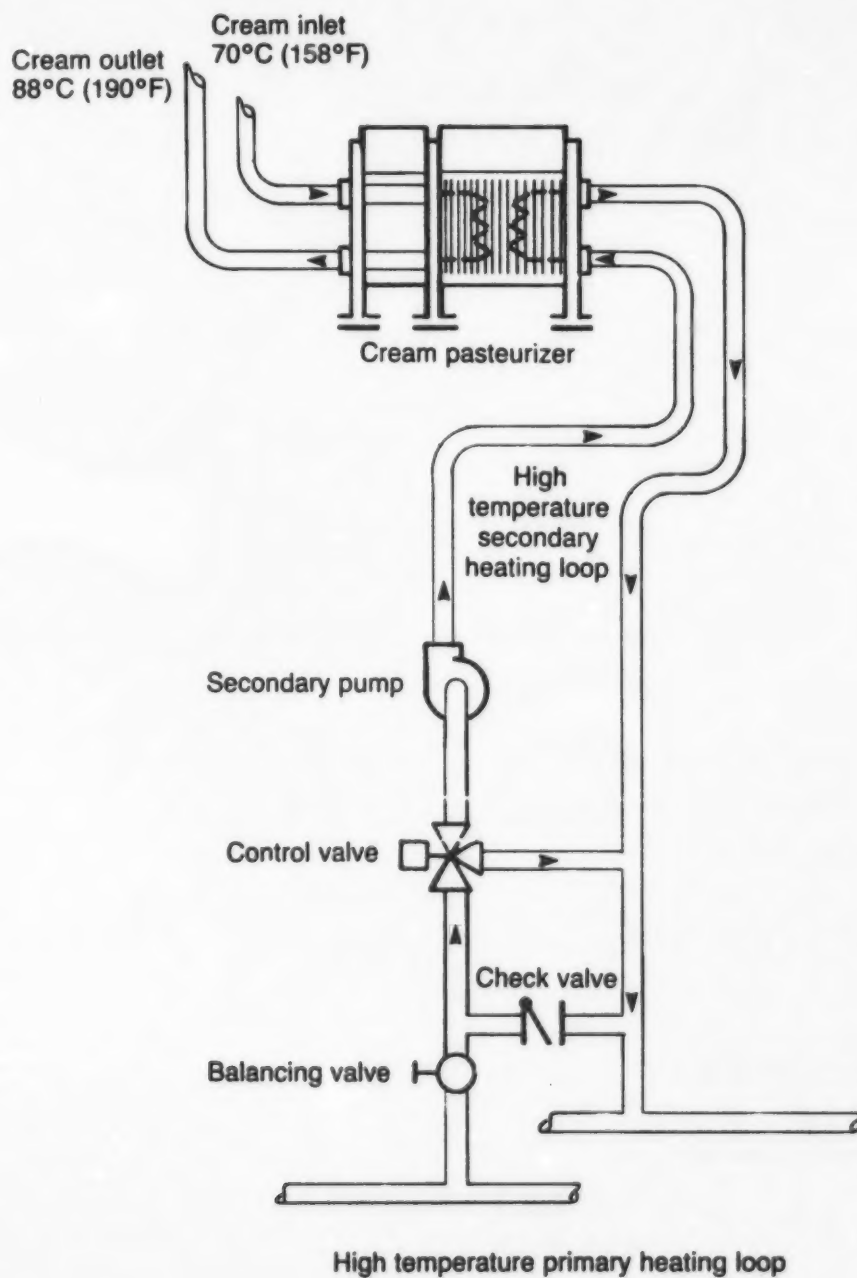
7.4.3 Capital cost of the installation

CREAM PASTEURIZATION

(Installation labor included)

Piping and accessories	3 500 \$
Secondary pump	2 300
Pump electrical supply	2 000
Control valve and accessories	5 000
Flow meter	1 500
Thermometers and pressure gages	2 500
Piping insulation	1 000
Sub total:	17 800
Administration: 15 %	2 700
Profit: 10 %	2 000
Total capital cost:	22 500 \$

Figure 7.4 Cream pasteurization schematic





7.4.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	14 300 \$
- Cream pasteurization	22 500
Total capital cost:	36 800 \$

ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
- Recovered energy cost	1,17¢/kWh
Unitary saving	1,39¢/kWh

- Heat exchanger capacity:	84 kW
- Expected hourly energy saving:	1,17 \$
- Operating hours:	5 100 hours

- Expected yearly saving:	5 967 \$
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iii- Return on investment

- Simple payback period:

$$\frac{36\,800\ \$}{5\,967\ \$} = 6,2\ \text{years}$$



7.5 Boiler feed water preheating

7.5.1 General

Fossil fuel generated steam is used for most of the heating requirements in the processes. Due to the nature of the processes involved, steam is almost always directly injected into the heated product. Large quantities of water make-up are therefore required to replace the lost condensate in the processes.

Actually, the major condensate return comes from the first and second effect of the evaporator. If a good maintenance program is implemented in order to eliminate the steam trap leaks, the average condensate return temperature can be maintained at 68°C (155°F). Most boiler feed pumps could handle condensate up to a 93°C (200°F) temperature level.

With the installation of the high temperature heat pump, the availability of a 93°C (200°F) primary heating loop can be used for boiler feed water preheating.

7.5.2 Description of the installation

All the condensates will be returned in a new accumulation reservoir. An auxiliary pump will be used to circulate the accumulated condensate in a new heat exchanger. After being heated, the condensate will be fed in the actual condensate return tank.



No control will be used for modulation of the capacity of the heat exchanger. The maximum heat recovery is always required.

The heating water flow will be regulated by a balancing valve which will be calibrated for the exact heating flow required. Flow meters will be used to achieve an accurate calibration.

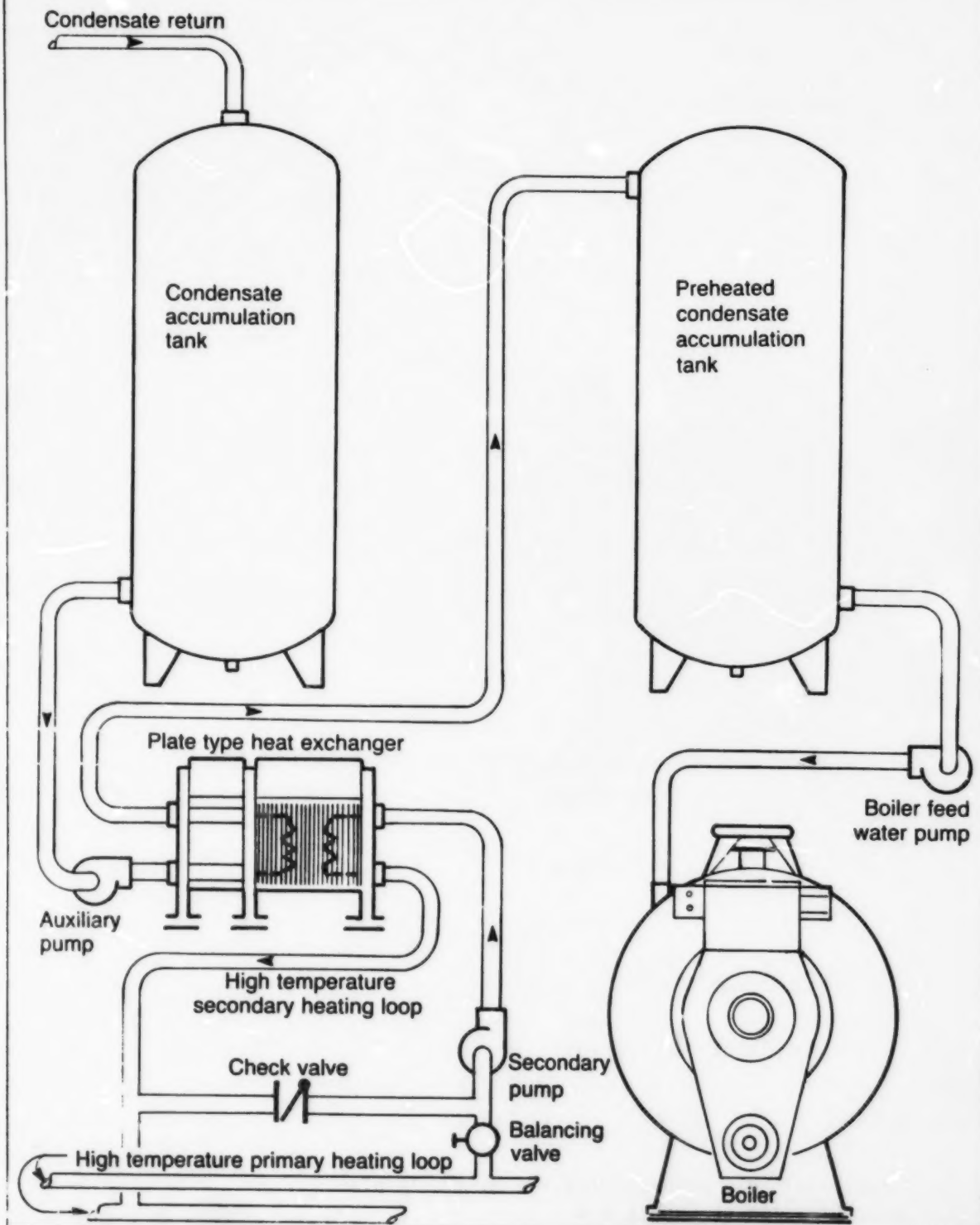
The hot water supply will either be pumped in the heat exchanger by a secondary loop circulation pump or it will be directly by-passed in the primary loop return. Figure 7.5 shows a schematic of this installation.

7.5.3 Capital cost of the installation

BOILER FEED WATER PREHEATING (Installation labor included)

Heat exchanger	10 200 \$
Piping and accessories	5 300
Secondary pump	1 700
Pump electrical supply	2 000
Flow meter	1 500
Piping insulation	700
Thermometers and pressure gages	500
Auxiliary pump	700
Sub total:	22 600
Administration: 15 %	3 400
Profit: 10 %	2 600
Total capital cost:	28 600 \$

Figure 7.5 Boiler feed water preheating schematic



7.5.4 Profitability analysis

i- Capital cost

- Share of the heat pump installation	29 600 \$
- Feed water preheating	28 600

Total capital cost:	<u>58 200 \$</u>
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ii- Expected energy savings

- Actual energy cost (fossil fuel generated steam)	2,56¢/kWh
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- Recovered energy cost	1,17¢/kWh
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Unitary saving	<u>1,39¢/kWh</u>
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- Heat exchanger capacity:	176 kW
- Expected hourly energy saving:	2,45 \$
- Yearly operating hours:	7 000 hours

- Expected yearly saving:	17 150 \$
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iii- Return on investment

- Simple payback period:

$$\frac{58\,200\ \$}{17\,150\ \$} = 3,39\ \text{years}$$



8. OVERALL PROFITABILITY OF THE INSTALLATION

8.1 Method of evaluation

The selection of any heat recovery system should be based on a compromise between its performance and economic merits. The life cycle cost evaluation of several design alternatives will take into account simultaneously all the economic factors:

- Initial capital cost
- Energy saving
- Operating costs
- Taxes
- Interest rate
- Energy escalation rate
- etc....

This economic evaluation method does not imply the lowest initial cost system; instead, it directs a decision toward a system with the lowest long term costs.

At this stage of the design, we propose the commonly used method of evaluation which is identified as the "years to payback". As long as we agree that years to payback is reasonable, this will be the determinant factor in the choice of one alternative. Later on, when more accurate data will be available, a thorough analysis of all the economic inputs can be made.



8.2 Summary of the profitability analysis

The following tables show the summary of all the installation costs together with the expected savings for each alternative. In order to achieve an accurate economic evaluation of the low temperature or the high temperature heat pump installation, the years to payback will be based on the expected saving and the assigned share of the initial capital cost.

We achieve a fairly accurate figure of the expected energy savings with the difference between the actual cost of the energy supply and the heat pump operation cost respectively to each of the process modification. Two modes of calculation are shown because the two electricity rates could be used: one is the normal rate structure and the other is a special rate created to promote the sale of an excess electricity production capability of the actual Hydro-Quebec installations. This new rate is less expensive than the usual one; at a cost of 1,35¢/kWh as compared to the average normal cost of 3,5¢/kWh.

We did not know yet if the energy supplied to the new heat pumps will be eligible to be calculated with the special rate. One of the restrictions is that the supplied energy must replace fuel oil. According to the proposed heat pump installation, the recovered energy will be used to replace some electricity and some heavy grade oil supply. Therefore, some negotiating will be required with the Hydro people to determine what portion, if any, will be applicable to the excess electricity rate.



The preliminary figures indicate a net profitability of the system.
The years for payback are as follows:

$$\begin{aligned}\text{Simple payback} &= \frac{\text{Total initial cost}}{\text{Total expected energy savings}} \\ &= \frac{855\,000 \$}{283\,400 \$/\text{years}} \\ &= 3,59 \text{ years}\end{aligned}$$

With the assumption of a 35 000 \$ yearly expense for the maintenance of the whole heat recovery installation, the payback period could be extended to 4,0 years.

TABLE 8.1 HIGH TEMPERATURE HEAT PUMP ECONOMIC ANALYSIS SUMMARY

	Capital cost \$	Capital cost including heat pump share \$	Total recovered heat capacity kW	Expected hourly saving		Yearly expected operating period hours	Expected yearly saving		Payback period (2) years
				rate 1 \$	rate 2 \$		rate 1 \$	rate 2 \$	
HEAT PUMP AND AUXILIARIES	247 000								
DRYER PREHEATING	48 200	287 300	580	13,51	17,66	5 100	68 920	90 100	4,17
CAN STERILIZER PREHEATING	59 000		322	4,48	6,80	1 000	4 480 (1)	6 800 (1)	13,25
WHOLE MILK PREHEATING	56 300		370	5,14	7,82	1 000	5 140 (1)	7 820 (1)	11,0
CREAM PASTEURIZATION	22 500	36 800	84	1,17	1,78	5 100	5 967	9 075	6,2
BOILER FEEDWATER PREHEATING	28 600	58 200	176	2,45	3,71	7 000	17 150	25 970	3,39
TOTAL ASSIGNED CAPITAL COST:		382 300 \$				TOTAL YEARLY SAVING:	92 037 \$	125 145 \$	

SIMPLE PAYBACK PERIOD FOR THIS PART OF THE INSTALLATION: $\frac{382\ 300}{92\ 037} = 4,15$ years (2)

Note (1) This figure is not included in the total.

(2) The payback period shown is based on expected savings with rate 1 (Hydro rate M).
Rate 2 is the special excess electricity rate.

TABLE 8.2 LOW TEMPERATURE HEAT PUMP ECONOMIC ANALYSIS SUMMARY

	Capital cost \$	Capital cost including heat pump share \$	Total recovered heat capacity kW	Expected hourly saving		Yearly expected operating period hours	Expected yearly saving		Payback period (2) years
				rate 1 \$	rate 2 \$		rate 1 \$	rate 2 \$	
HEAT PUMP AND AUXILIARIES	249 000								
DRYER PREHEATING	46 500	236 700	696	18,94	22,82	5 100	96 594	116 382	2,45
CAN STERILIZER PREHEATING	58 500		351	6,24	8,23	1 000	6 240 (1)	8 230 (1)	9,4
CONCENTRATE PREHEATING	31 200	40 200	102	1,82	2,41	6 000	10 920	14 460	3,66
CLEANING WATER HEATING	112 000	125 800	146	2,60	3,43	7 500	19 500	25 725	6,45
SPACE HEATING	70 000	70 000	200	7,44	9,81	2 600	19 350	25 510	3,6
TOTAL ASSIGNED CAPITAL COST:		472 700 \$		TOTAL YEARLY SAVING:			141 364 \$	182 077 \$	

SIMPLE PAYBACK PERIOD FOR THIS PART OF THE INSTALLATION: $\frac{472\ 700}{146\ 364} = 3,23\ \text{years (2)}$

Note (1) This figure is not included in the total.

(2) The payback period shown is based on expected savings with rate 1 (hydro rate M).
Rate 2 is the special excess electricity rate.



9. AREAS FOR RESEARCH AND DEVELOPMENT

9.1 General

A thorough analysis of all the possible design improvements should be made if the plant owner or the designer wants to be sure that the proposed installation will be the best for the intended use. This study should look forward for the last development in the applied technology. In some cases, it will be more advisable for the plant owner to wait for a promising breakthrough that will obsolete the current technology.

In the milk industry, since the energy crisis, several new processes have been developed to improve the overall efficiency of the milk transformation. For example, the reversed osmosis process is actually a very efficient technology used for a primary concentration of the whole milk. Despite the undeniable advantage of this revolutionary milk concentration method, modification of actual evaporating equipment can be a more profitable investment than the complete change of the process involved.

This discussion will be essentially focussed on the multiple effects vacuum evaporator. Due to the currently used technology and the tremendous amount of energy involved, it is likely that this apparatus shows the best opportunity for a standardized design of heat pump applications. The analysis of the several research and development opportunities will primarily describe the characteristics of the evaporator itself followed by a brief review of the most promising improvements that could be implemented.

Because of the nature of the drying process, the possible recovery of the latent heat content of the exhausted air in order to be used for supply air preheating of the dryer is another interesting opportunity that should be studied in detail. Unfortunately, the exhausted air of the drying process carries an amount of milk dust which will eventually plug any type of heat exchanger. This dust clog-up of the exchanger surfaces is the major problem that should be solved before any discussion on probable heat pump application. Several approaches have been proposed and some of them have been implemented.

9.2 Description of the vacuum evaporator principles

Today's evaporators represent the successful application of a number of engineering principles. Originally, the evaporators were comparatively simple affairs in which the product flowed or was pumped through shell-and-tube heat exchangers in which some of the water was vaporized and then passed to a chamber where the vapor and liquid are separated. The vapors are directed to a barometric or surface condenser while the liquid is recirculated through the heat exchanger where more water is removed. Vacuum was maintained with mechanical pumps or steam-jet ejectors.

Falling film heat exchangers are used today in order to increase the rate of removal of water vapor and decrease the danger of localized overheating. Because of the sizable amount of energy consumed, evaporators are multistage and vapors removed from the products are utilized as a source of heat for additional evaporation in the other effects. Figure 9.1 shows a schematic of a quadruple effect evaporator with "Finisher" and jet condenser.



Based on the schematic of the quadruple effect evaporator, the operation is as follows:

The product is primarily heated by the evaporated steam in each of the separation chambers of the multiple effects. Then, the product is pumped through the preheating coils and the tubular pasteurizer and fed to the top of the first effect calandria, where a special distributor ensures a uniform and equal distribution of the liquid to the heating tubes.

Evaporation takes place while the liquid in a uniform thin film runs down the inside surface of the tubes, gaining in velocity due to the force of gravity and the vapour developed which also descends with increasing velocity.

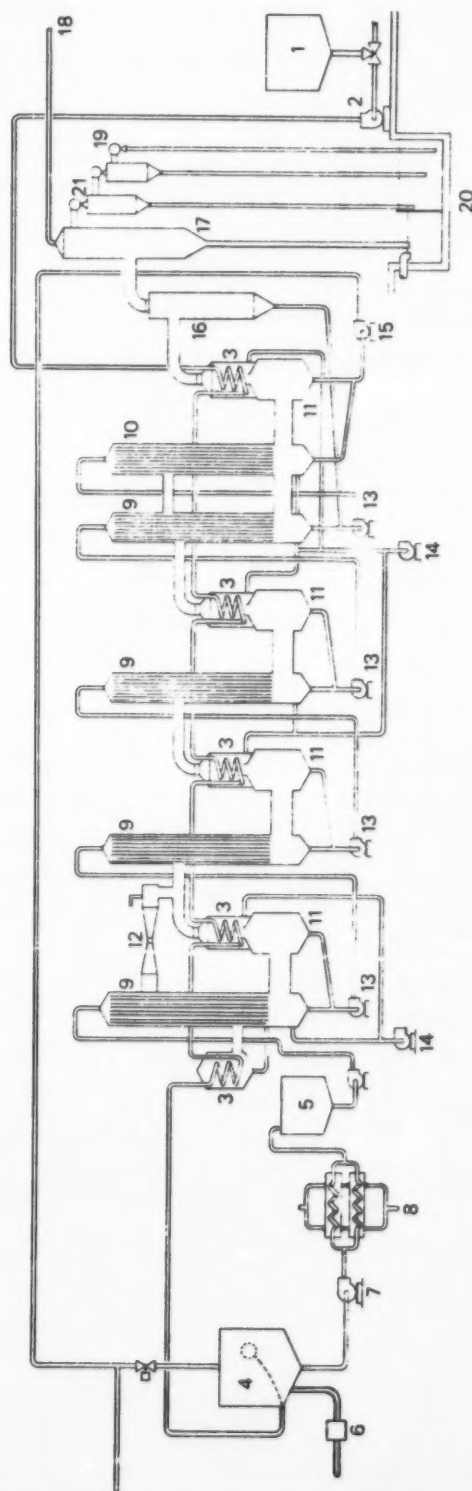
From the bottom of the calandria, the liquid is pumped to the top of the second effect calandria, and with increasing concentration the liquid continues to all the calandrias and the "Finisher", and is finally discharged.

The vapour which has developed in the first effect calandria passes to the first effect separator where the last drops of milk are separated from the vapour and heat transmitted from the vapour to the preheating coils situated in the top of the separator.

After the separator, the vapour stream divides and approx. half of it is drawn into the thermo compressor, where the vapour is compressed with live steam and then used as a heating medium in the first effect calandria.

Figure 9.1

Quadruple effect Evaporator with Finisher and Jet Condenser



1. Circulation tank
2. Product feed pump
3. Preheaters
4. Balance tank
5. Retaining tank
6. Automatic water supply
7. Product feed pump
8. Tubular pasteurizer
9. Calandrias
10. "Finisher"
11. Vapour separators
12. Thermo compressor
13. Circulation pumps
14. Condensate pumps
15. Concentrate pump
16. Demister
17. Barometric condenser
18. Cooling water
19. High pressure steam
20. Hot well
21. Vacuum steam jet ejector

The remaining vapour enters the second effect calandria where it is used as a heating medium, and so on through all the evaporator effects.

The vapour produced in the last effect is carried to the demister and finally to the jet condenser.

The passage of the vapour through the evaporator is produced by the temperature and pressure differentials between each effects.

9.3 Heat pump application with indirect refrigerant contact

The essential of the proposed installation uses components of proven design from established manufacturers. Recognizing that readily available and proven equipment is to be used to permit early implementation, a thorough analysis of the possible utilisation of the heat pump as the main energy source of the evaporator should be made. This arrangement will require special research on the possible modification of the first effect calandria in order to use water instead of steam. A standardized design could be developed for the whole milk industry.

Figure 9.2 shows a schematic of a concentration system using a heat pump. It differs from the original evaporator operation in the following ways: the product is heated by circulated hot water which in turn is heated by hot refrigerant gases (high pressure side). The vapor of the product is condensed by direct contact with cold water in the barometric condenser, the water having been cooled by the boiling refrigerant (low side).

Figure 9.2
Heat pump installation for a vacuum evaporator

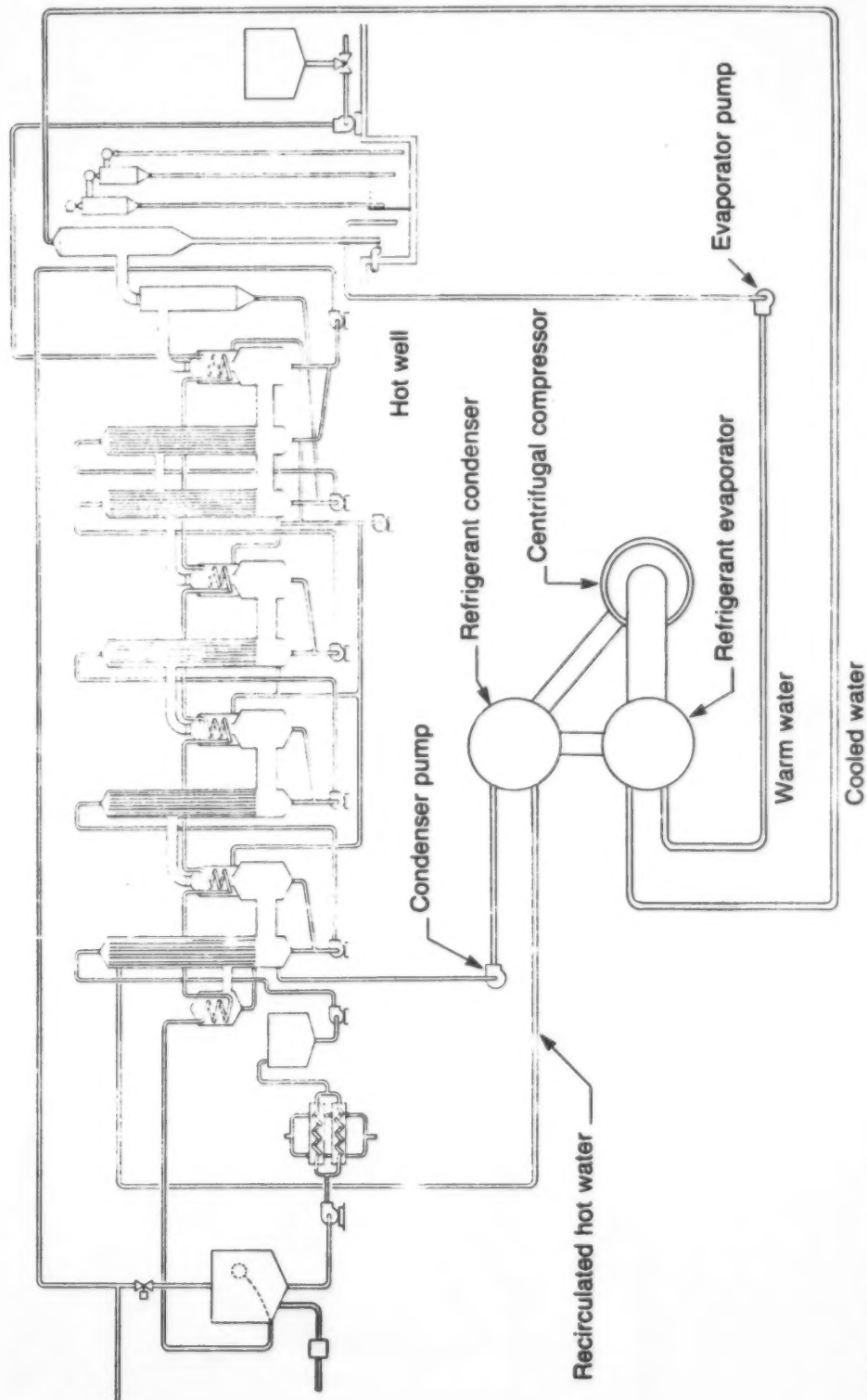
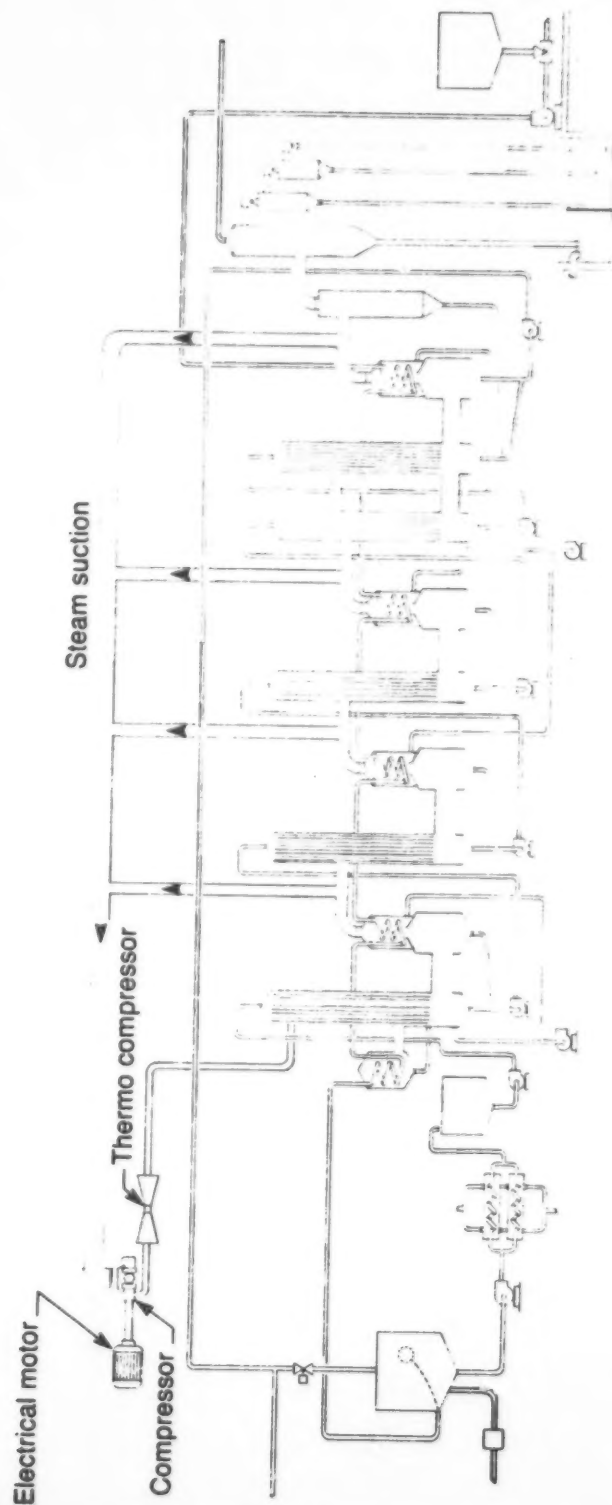


Figure 9.3
Vacuum evaporator with mechanical vapor recompression





The advantages of the system are:

1. Centrally located standard unitary refrigerant equipment can be used.
2. Controls and equipments can be standard.
3. Refrigerant lines are short and hold-up is low.
4. Evaporators need not be designed to hold refrigerant.
5. No danger of refrigerant contaminating the product.
6. Very little steam is required.

Direct refrigerant contact could be used to improve the efficiency of the whole installation but evaporating equipment would have to be constructed to withstand refrigerant pressure. Contamination of the product could also happen if any leak develops in the evaporator.

To our knowledge, it would be the most probable improvement to the proposed design if modifications of evaporators could be kept in an acceptable range of capital costs. The improvement could also be standardized to all evaporator installations.

9.4 Vapour recompression

Figure 9.3 shows a schematic system in which the vapor from the product, instead of being condensed, is compressed to a higher temperature and pressure and used to evaporate more water. The vapor could be compressed by a booster steam ejector or by mechanical vapor recompression.



In the booster steam ejector often called "Thermo compression" high pressure motive steam is consumed in a ratio that generally makes the resulting low pressure steam fairly expensive. Comparatively, the mechanical vapor recompression is more attractive from an economic efficiency standpoint.

The concept of the MVR arrangement is the same as a heat pump, it differs only in the type of refrigerant which in that case is the evaporated steam itself. The MVR approach generally operates with about the same COP as heat pumps. This technic is now being widely used in Europe as a modified heat pump concept.

Despite the promising overall efficiency of the mechanical vapor recompression, it has several inherent disadvantages:

1. Considerable maintenance is required on the compressor due to corrosion, erosion and contamination from the evaporation process.
2. Larger volume required by the compressor in order to handle vacuum gases.
3. Capacity of the compressor had to be chosen for the exact requirements.
4. Special controls required for a reliable operation.
5. High cost of the compressor installation and the modifications to the evaporator.

Further research is required to be informed on the overall efficiency of the mechanical vapor recompression, as well as on the accurate evaluation of the probable implementation cost.

9.5 Generation of low pressure steam

Because of its high enthalpy content, steam is the traditional energy supplier for most of the industrial processes. As an alternative to the proposed primary and secondary hot water heating loops, low pressure steam, generated by a heat pump could be used directly in the actual distribution system. This opportunity could substantially lower the initial capital cost of the several installations needed for recovered heat utilisation.

To our knowledge, only one manufacturer of heat pump has developed a design and built a prototype which can produce low pressure steam. Based on the information received from the manufacturer, the wasted heat source should be at a 65°C (150°F) temperature level. This requirement is caused by the type of refrigerant used in the unit. Below this temperature, it would be a vacuum type evaporation.

In the plant studied, the heat source is at a 40°C (105°F) temperature level and most of the large steam users are fed by high pressure steam.

Research should be initiated in order to develop a new design that will use a two stage compression with a lower temperature heat source and a higher steam pressure output. These requirements will certainly have a negative impact on the overall COP of the installation.



10 IMPACT ON TOTAL ENERGY CONSUMPTION

The installation of two heat pumps in this milk process plant as proposed in this project will have a significant impact on the plant's energy requirements.

With the present production rates, the total annual energy savings will amount to 10 550 000 kWh. In this particular plant, 64 % of these savings are electrical savings and 36 % are fuel oil savings.

These savings represent a 20 % reduction of the total energy requirements of this plant. The cost avoidance of these savings amount to 238 400 \$ per year.

Based on production figures published in the dairy review by Statistics Canada, the powder milk output of the plant in Rivière Trois-Pistoles represents approximately 3 % of the national output of powder milk products. If this heat pump project would be implemented in all the powder milk plants of our country, the total energy saving would amount to 350 million equivalent kilowatthours. This saving represents a total value in 1983 of approximately 8 million dollars.

The installation of heat pumps in all the other dairy plants where evaporators are used for concentration purposes would bring savings more or less twice as high as the figures shown above.

Most of the savings shown are fossil fuel savings. Approximately 40 % would be heavy oil savings, 45 % natural gas savings and the remainder would be electrical energy saving.



Furthermore, similar heat pump applications could be found in other food process plants where evaporation processes are used.

There is no doubt that an implementation of the project proposed in this document will permit to verify the economics of a particular heat pump application. If the project proves to be economically sound, the same principle can be applied in a important sector of the present food industry.